Science 101:

Air Pollution - At Home and Around the Globe

Annmarie Eldering

June 22, 2009

Jim Steinfeldt / Michael Ochs / Getty Archives

Acknowledgements

- Reinhard Beer and the TES (Tropospheric Emission Spectrometer) team (John Worden, Kevin Bowman, Susan Kulawik, Ming Luo, Greg Osterman, Brendan Fisher, Bob Herman, Chris Boxe…)
- The TES postdoc team: Yunsoo Choi, Paul Hamer, Jeonghoon Lee, Tutu Aghedo, Richard Dupont, Damien Lafont
- Many more…….

Los Angeles is a Smog Capital!

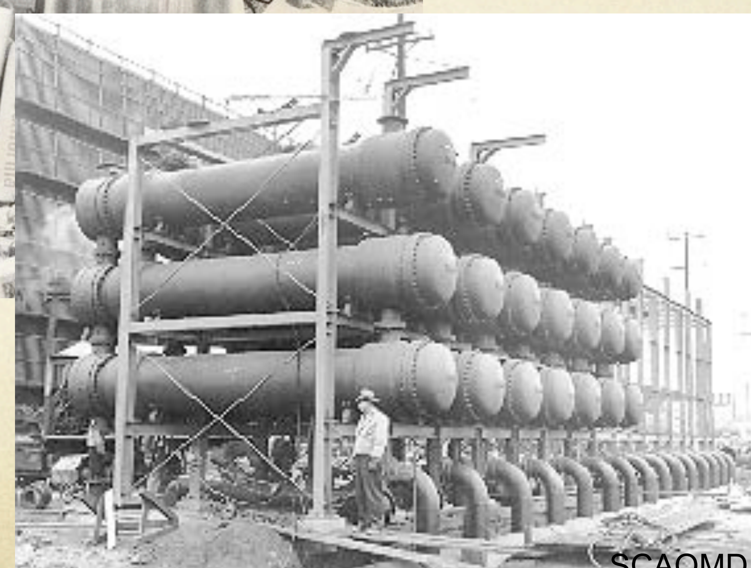
Protestors calling themselves the Smog-A-Tears carry banners and parade in gas masks through downtown Pasadena 1954. (Los Angeles Times)

Marion E. Lent makes her way to work as smog dims City Hall in this 1953 photo. (Los Angeles Times)

History of Smog in LA

LA Times

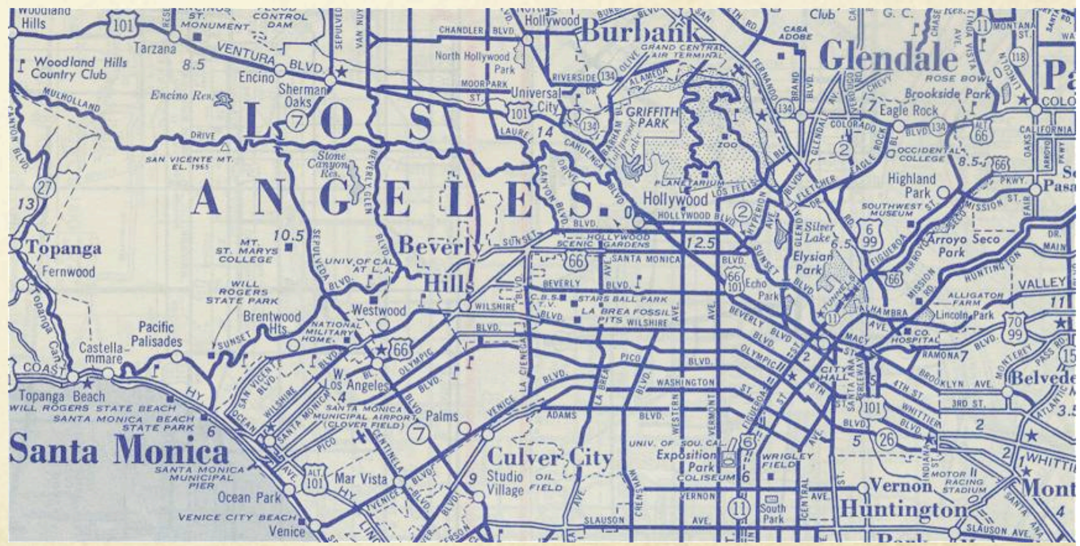
- Terrible air quality was noted in Los Angeles as early as the 1900's.
- Some controls were put in place, but with WWII and growth, air quality grew much worse in the 1940's.
- What was to blame?



SCAQMD

Possible Causes of Smog

- Incinerators and factory smoke were perceived as the problem
- An expert wrote in the LA Times, 1946, many uncontrolled sources contribute to the problem
- He made 23 recommendations for change
- Chemistry or politics of control?



Photochemical smog – what is it?

SCAQMD

- Smog = smoke + fog
- In 1948, Caltech Prof. Haagen-Smit looked at damage to plants

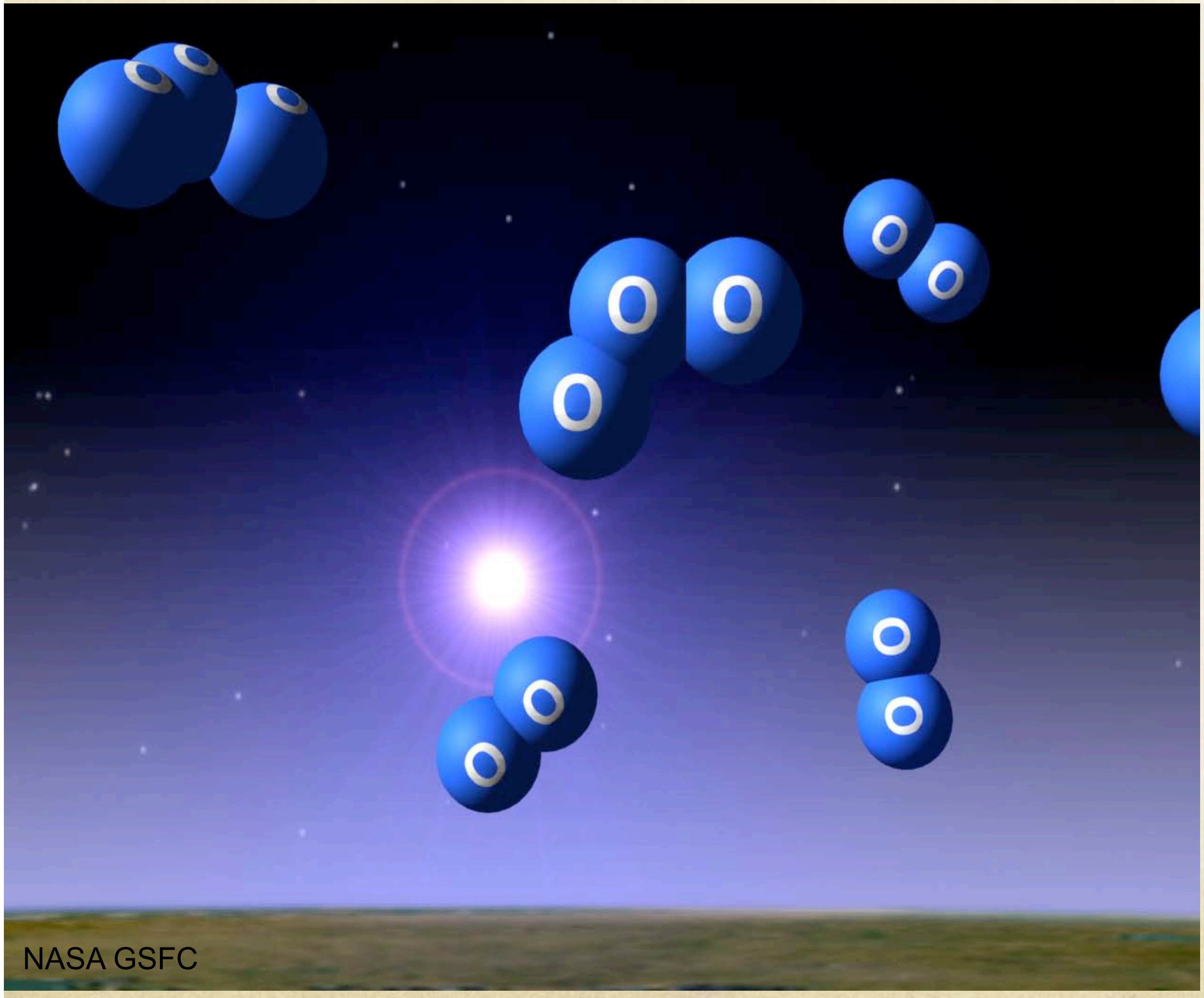
- Found that even with smoke controls, there was a bleach like smell in the air
- This air pollution was different from sulfur pollution of the Northeast US

Helmet Helps Smog Study

THE lady under this plastic headpiece is getting a dose of smog, made up of smoke and fog. Photoelectric cells attached to glassless goggles record blinks due to eye irritation. She reads a book to produce uniform reactions. The test is part of a study being made by Stanford Research Institute to find out more about the smog that often blots out Los Angeles' sunshine.

www.modernmechanix.com

Figuring out the ingredients



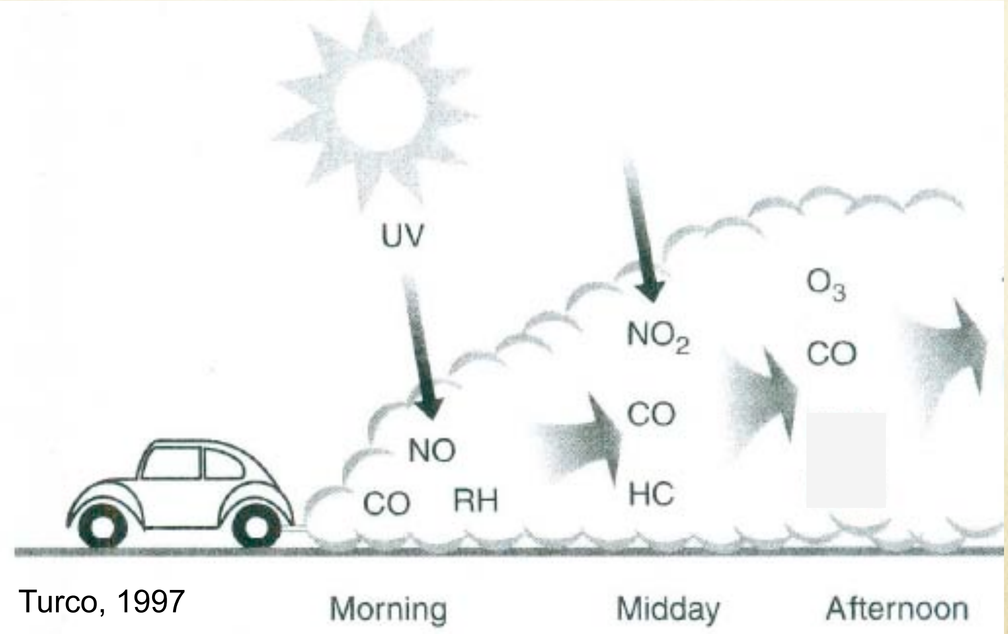
By 1950, Haagen-Smit figured out it was ozone!

Where did it come from?

By 1952, they found that ozone was not directly released to the atmosphere, but it formed there!!

A little chemistry

- Reactive Hydrocarbons + NO + sunlight → ozone + NO_2+ stable hydrocarbons

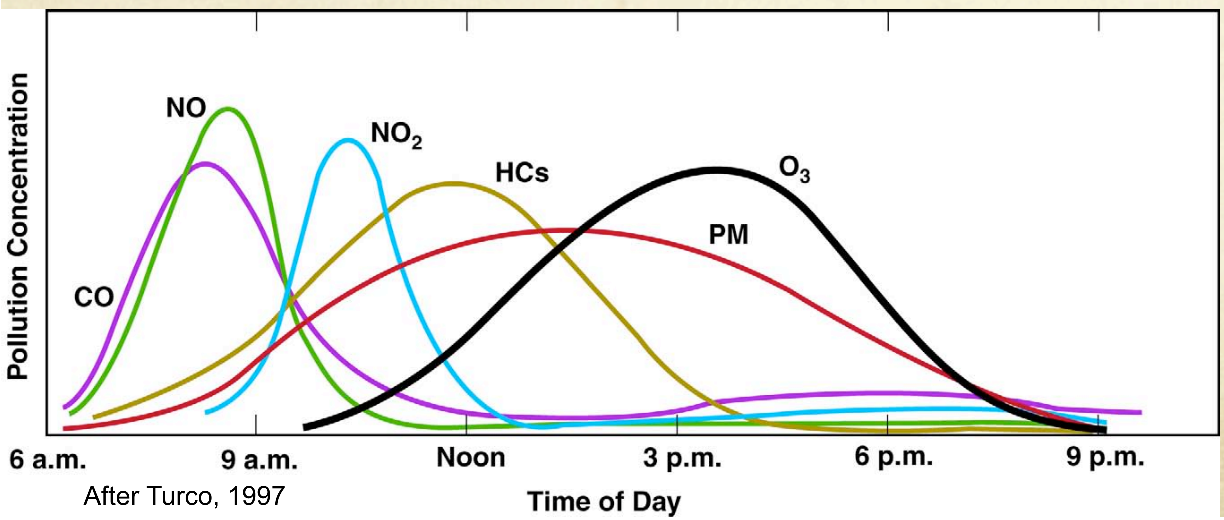


Turco, 1997

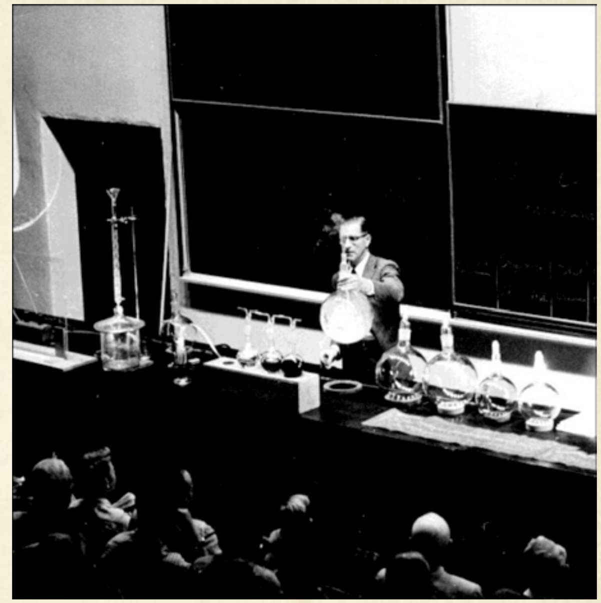
- Details
  - Reactive Hydrocarbons (RH) – from oil refineries, leaky gasoline storage, vegetation
  - HC – more stable forms of hydrocarbons
  - NO and NO_2 – from combustion
  - NO_2 – makes the 'brown cloud'
  - CO – from combustion and chemical reactions

Understanding more details

- Doubt
- Point the finger
- Figure out a plan!



After Turco, 1997

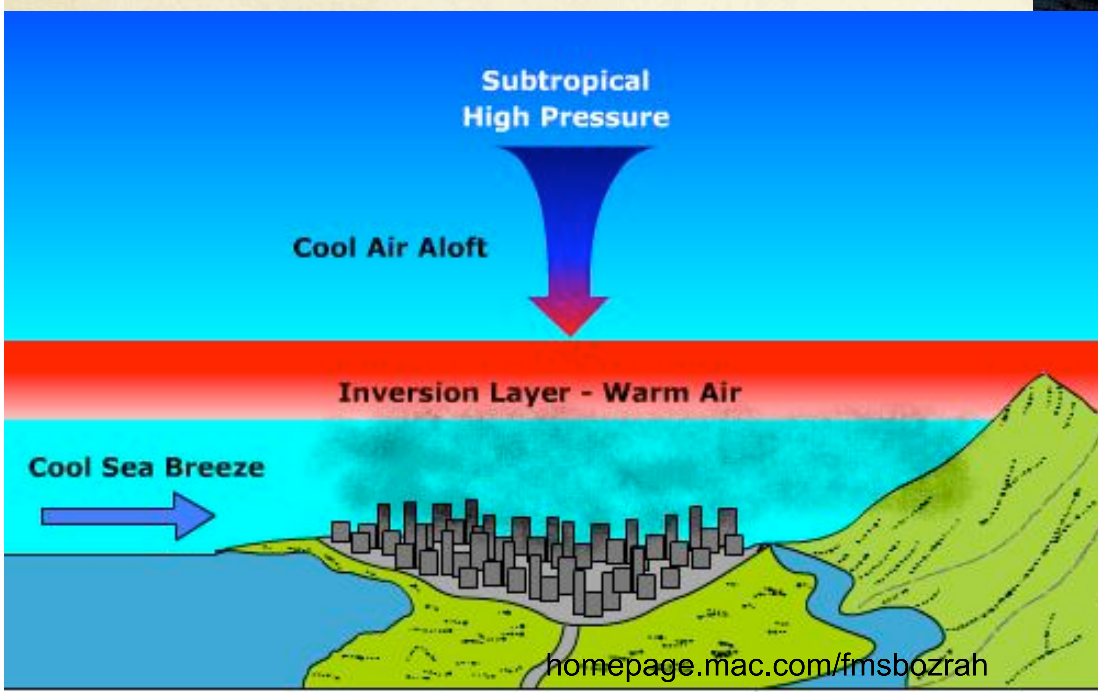


Arie Haagan-Smit demonstrates smog formation. (undated photo, Caltech Archives)

Other ingredients

- LA mountains and weather patterns trap the air

JPL



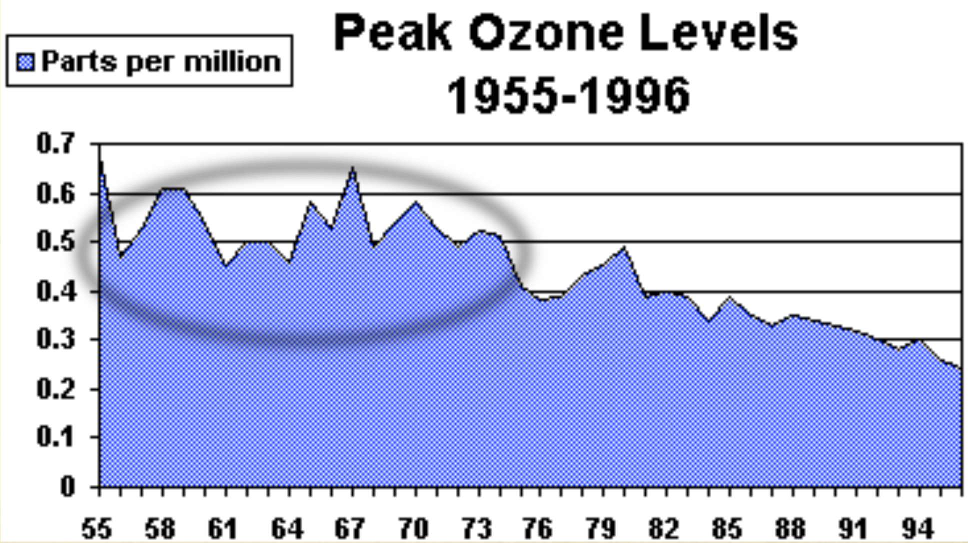
homepage.mac.com/fmsbozrah

JPL

The path to controlling the smog

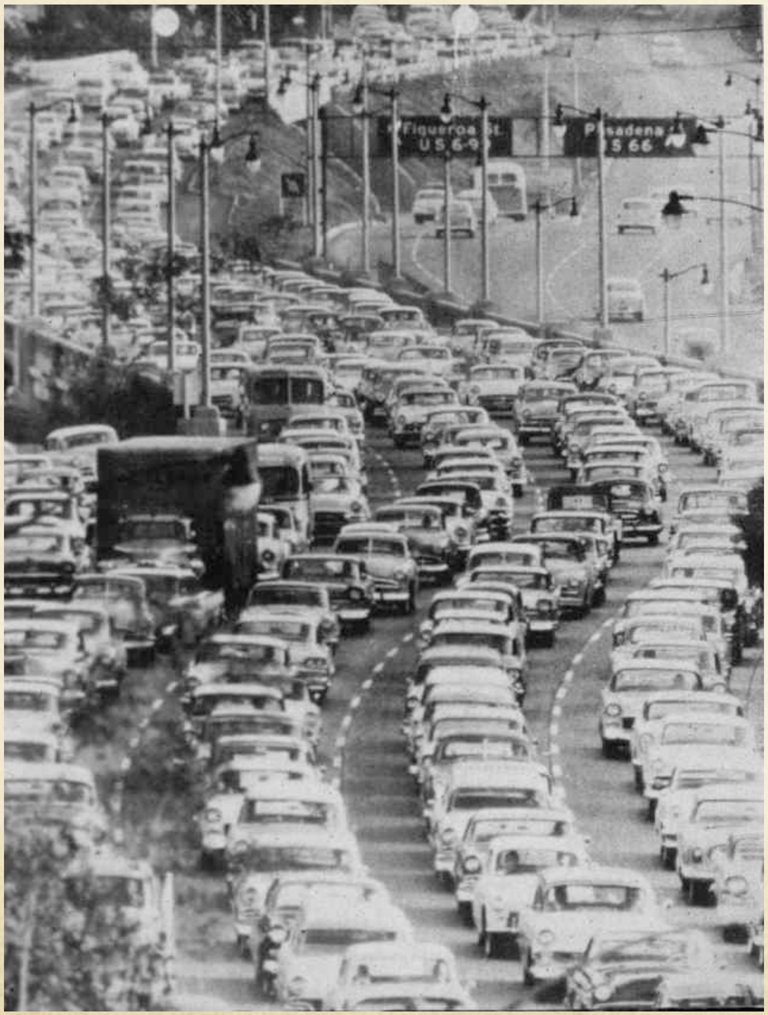
- Real change occurred in 1953
- Gasoline storage and filling of tanks were controlled
- In the 70's fuel pump nozzles had capture systems
- Solvents, power plants, landfills were regulated

- But, another change was needed!



SCAQMD

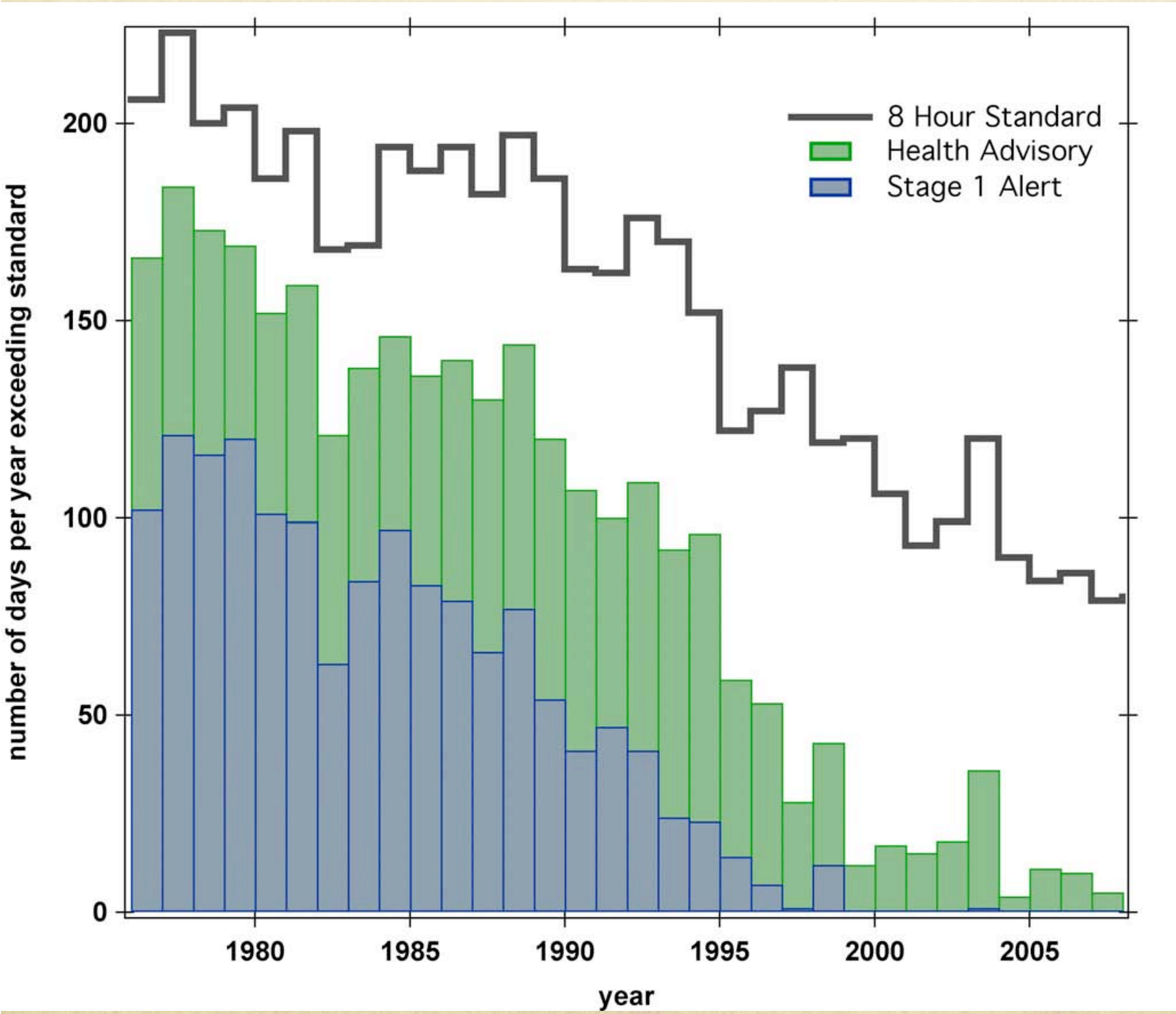
Controlling the car



- By the late 50’s the number of cars was increasing dramatically
- First regulated the crankcase – making vapors recycled (1963)
- Tailpipes regulated in the 60’s , catalytic converters required in 1975!!

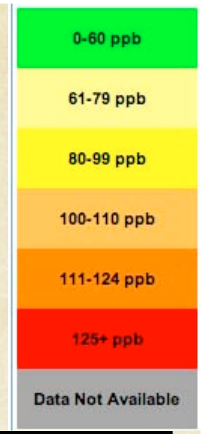
Los Angeles Freeway Traffic (1950s).
Courtesy of the US Environmental Protection Agency.

Trends in ozone in LA

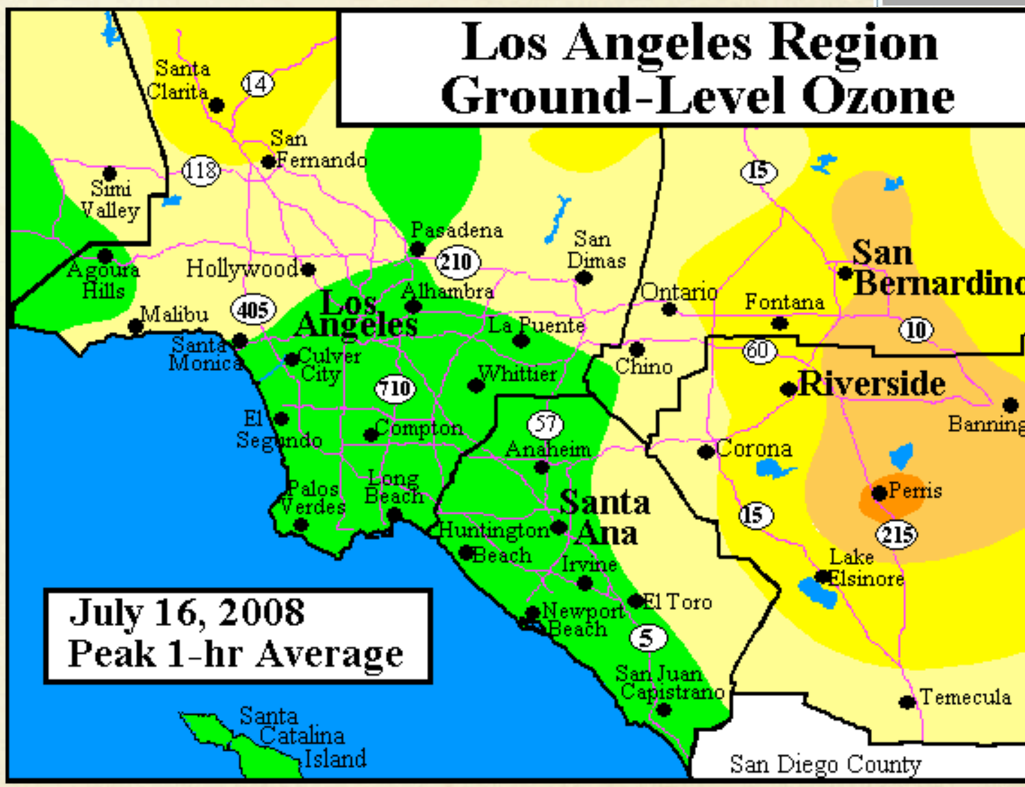


- 1 ppm =
  1000 ppb
- Old 8 Hr Std = **0.08 ppm**
- Health Advisory issued if 1 Hr concentration exceed **0.15 ppm**
- Stage 1 alert – 1 hr conc. Of **0.20 ppm**

Characterizing the ozone



- Now we are used to seeing maps of ozone concentrations
- Most measurements at ground based monitoring sites



US EPA

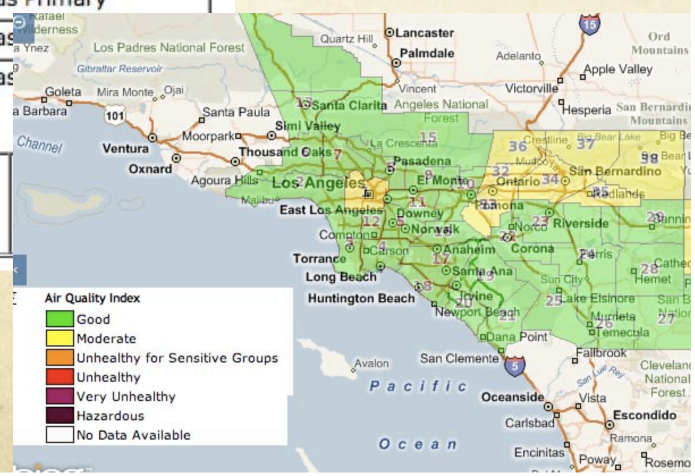
All the pollutants

National Ambient Air Quality Standards

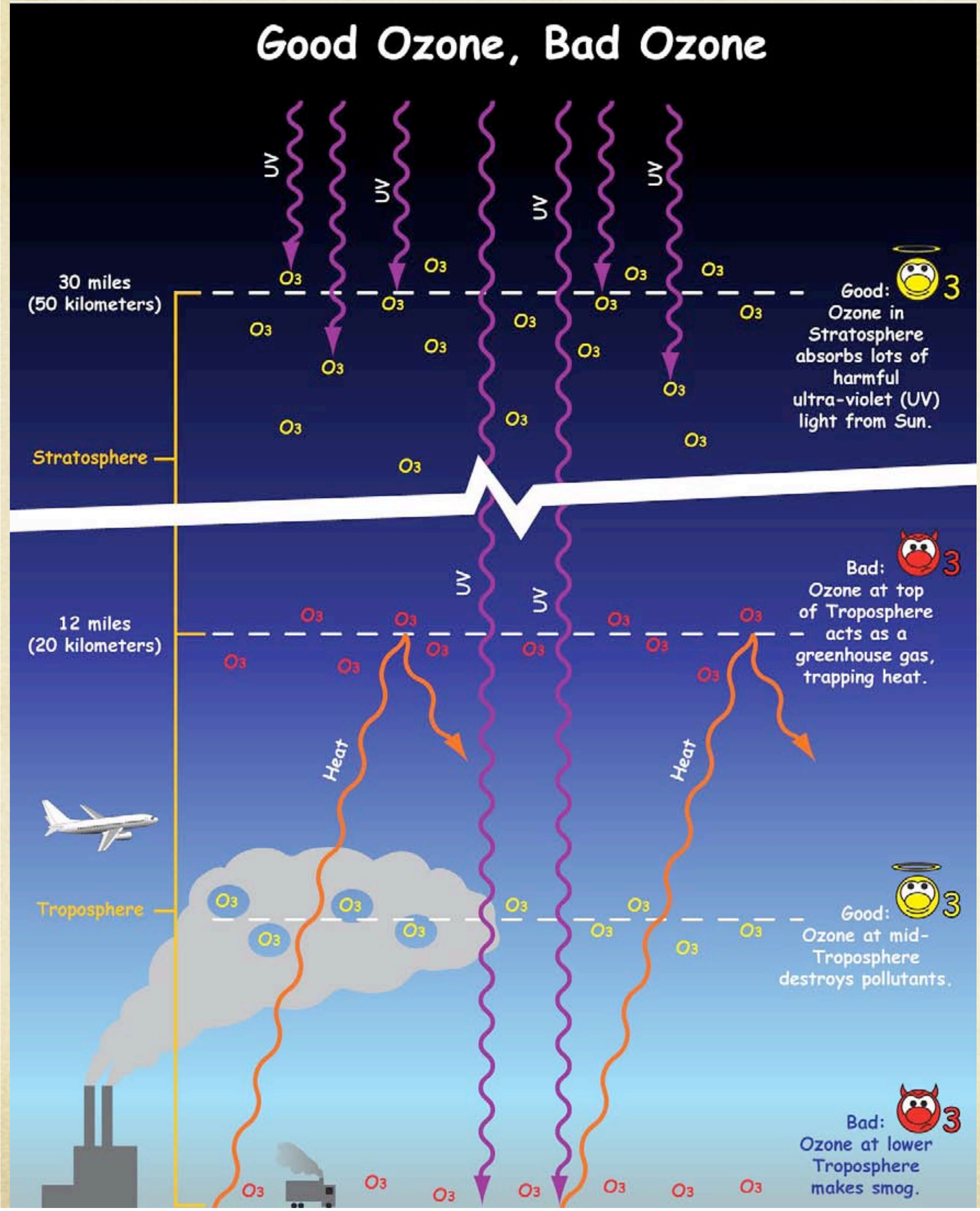
	Primary Standards		Secondary Standards	
Pollutant	**Level**	**Averaging Time**	**Level**	**Averaging Time**
Carbon Monoxide	9 ppm ($10\ mg/m^3$)	8-hour (1)	None	
	35 ppm ($40\ mg/m^3$)	1-hour (1)		
Lead	$0.15\ \mu g/m^3$ (2)	Rolling 3-Month Average	Same as Primary	
	$1.5\ \mu g/m^3$	Quarterly Average	Same as Primary	
Nitrogen Dioxide	0.053 ppm ($100\ \mu g/m^3$)	Annual (Arithmetic Mean)	Same as Primary	
Particulate Matter (PM_{10})	$150\ \mu g/m^3$	24-hour (3)	Same as Primary	
Particulate Matter ($PM_{2.5}$)	$15.0\ \mu g/m^3$	Annual (4) (Arithmetic Mean)	Same as Primary	
	$35\ \mu g/m^3$	24-hour (5)	Same as Primary	
Ozone	0.075 ppm (2008 std)	8-hour (6)	Same as Primary	
	0.08 ppm (1997 std)	8-hour (7)	Same as	
	0.12 ppm	1-hour (8) (Applies only in limited areas)	Same as	
Sulfur Dioxide	0.03 ppm	Annual (Arithmetic Mean)	0.5 ppm ($1300\ \mu g/m^3$)	
	0.14 ppm	24-hour (1)		

US EPA

- Six gases are regulated by the EPA
- They combine them into an Air Quality Index, that is often reported in the newspaper

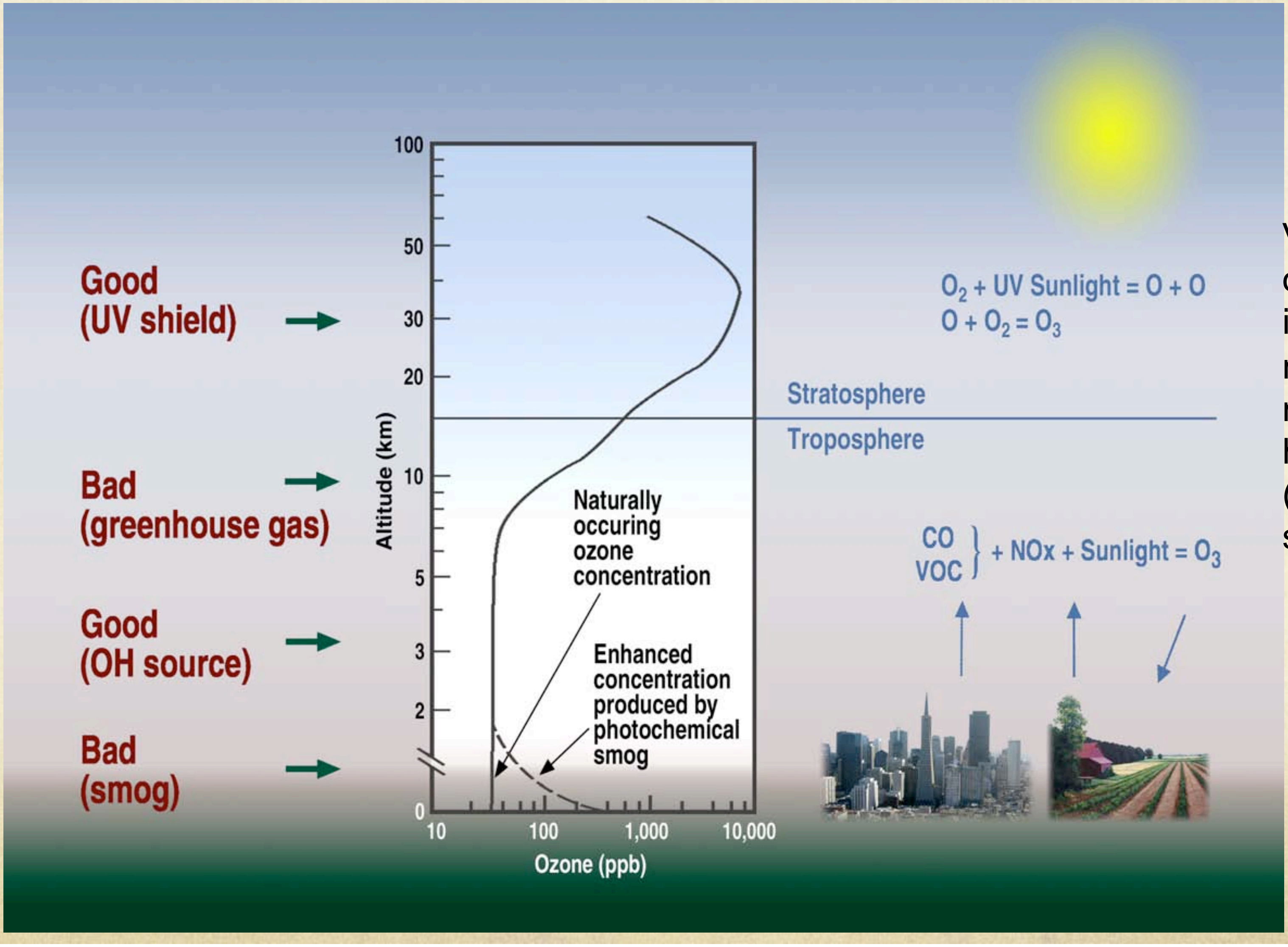


Air Quality Index (AQI) Values
When the AQI is in this range:
0 to 50
51 to 100
101 to 150
151 to 200
201 to 300
301 to 500



The other ozone

How it is distributed ?

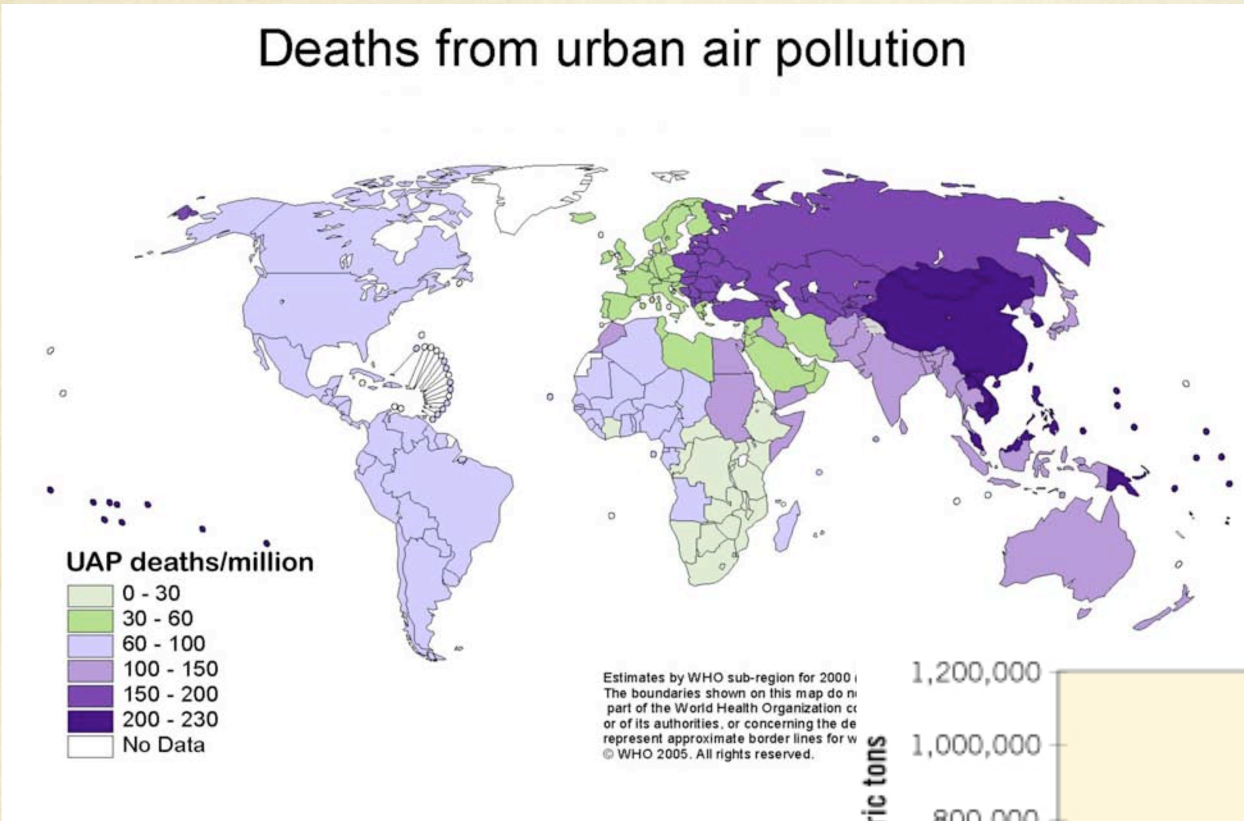


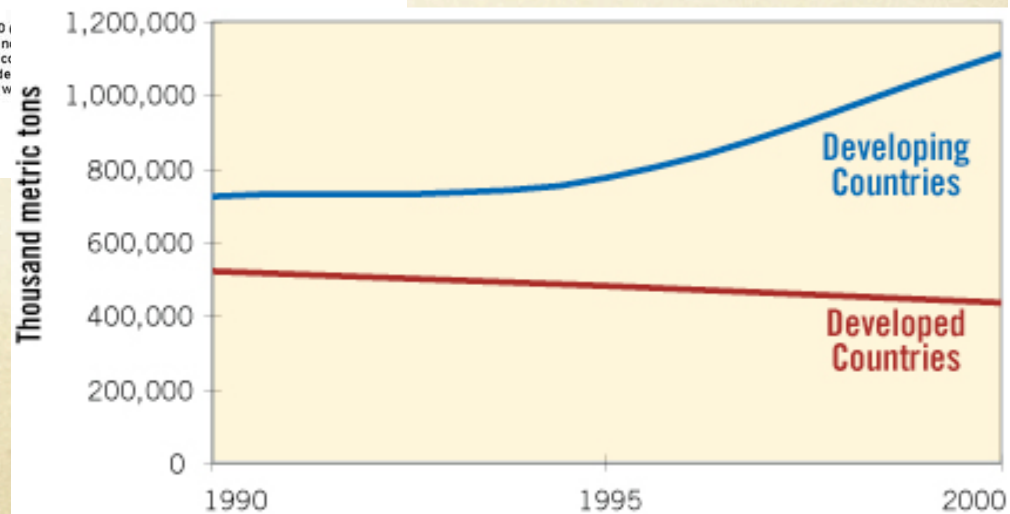
VOCs (volatile organic carbon) is another name for reactive hydrocarbon (RH on earlier slide)

Where else?

- Many other places have the right ingredients
  - Emissions
  - Sunlight
  - Trapping topography…
- Mexico City, DC to Boston, Beijing, and the list goes on……

Many places have pollution





Total of sulfur dioxide, nitrogen oxides, and non-methane VOC emissions
Source: EarthTrends, 2005

Cities are growing

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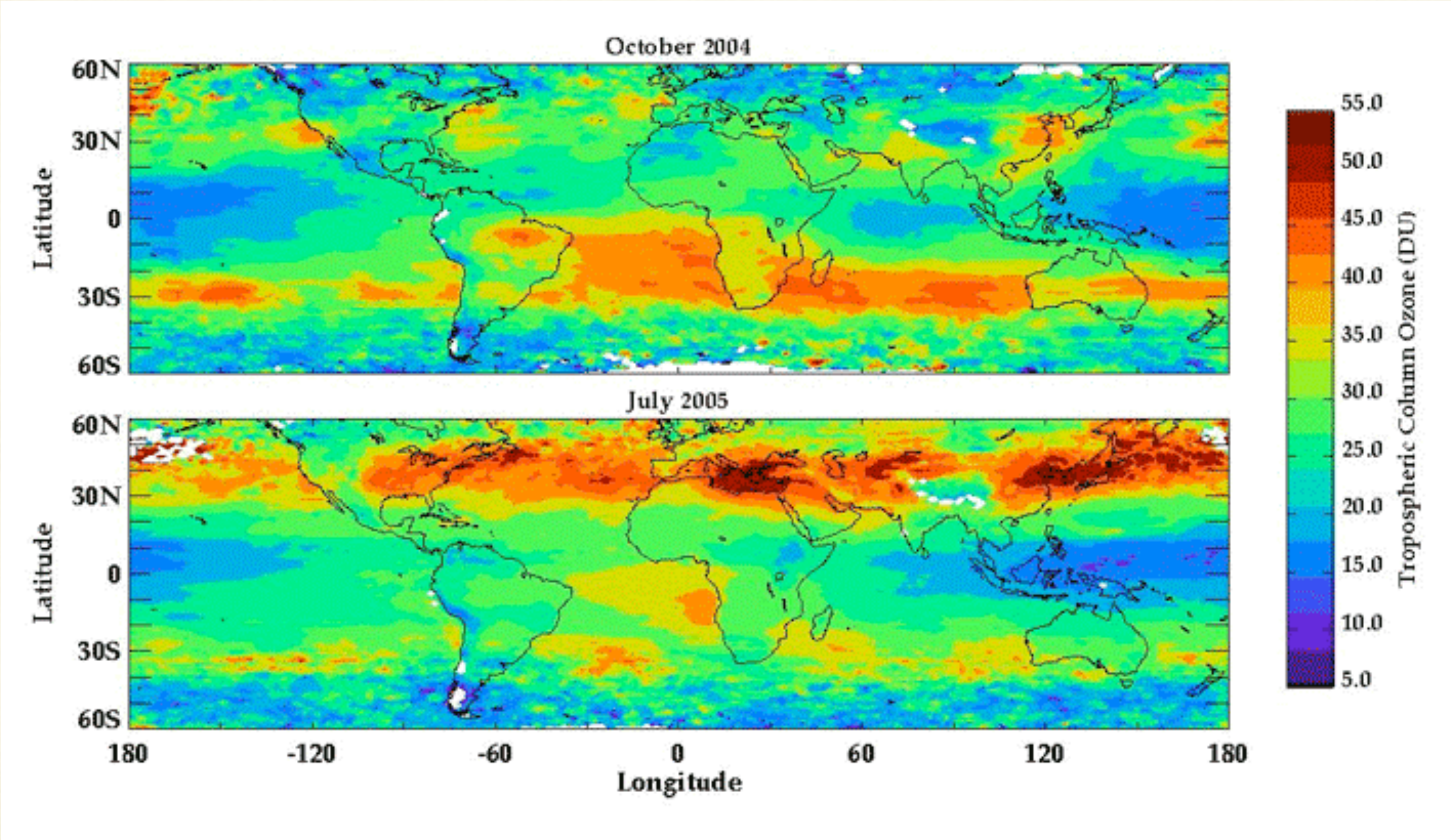
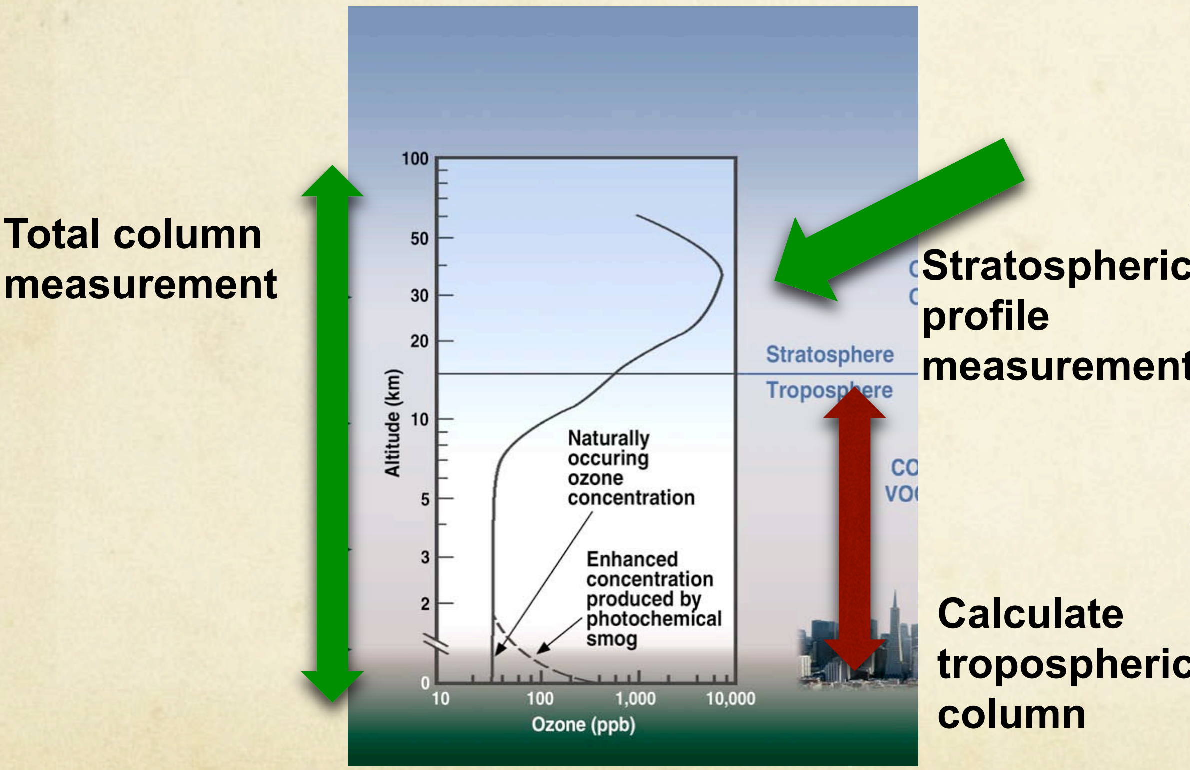
What about global ozone?



Monthly maps of ozone from EOS Aura measurements

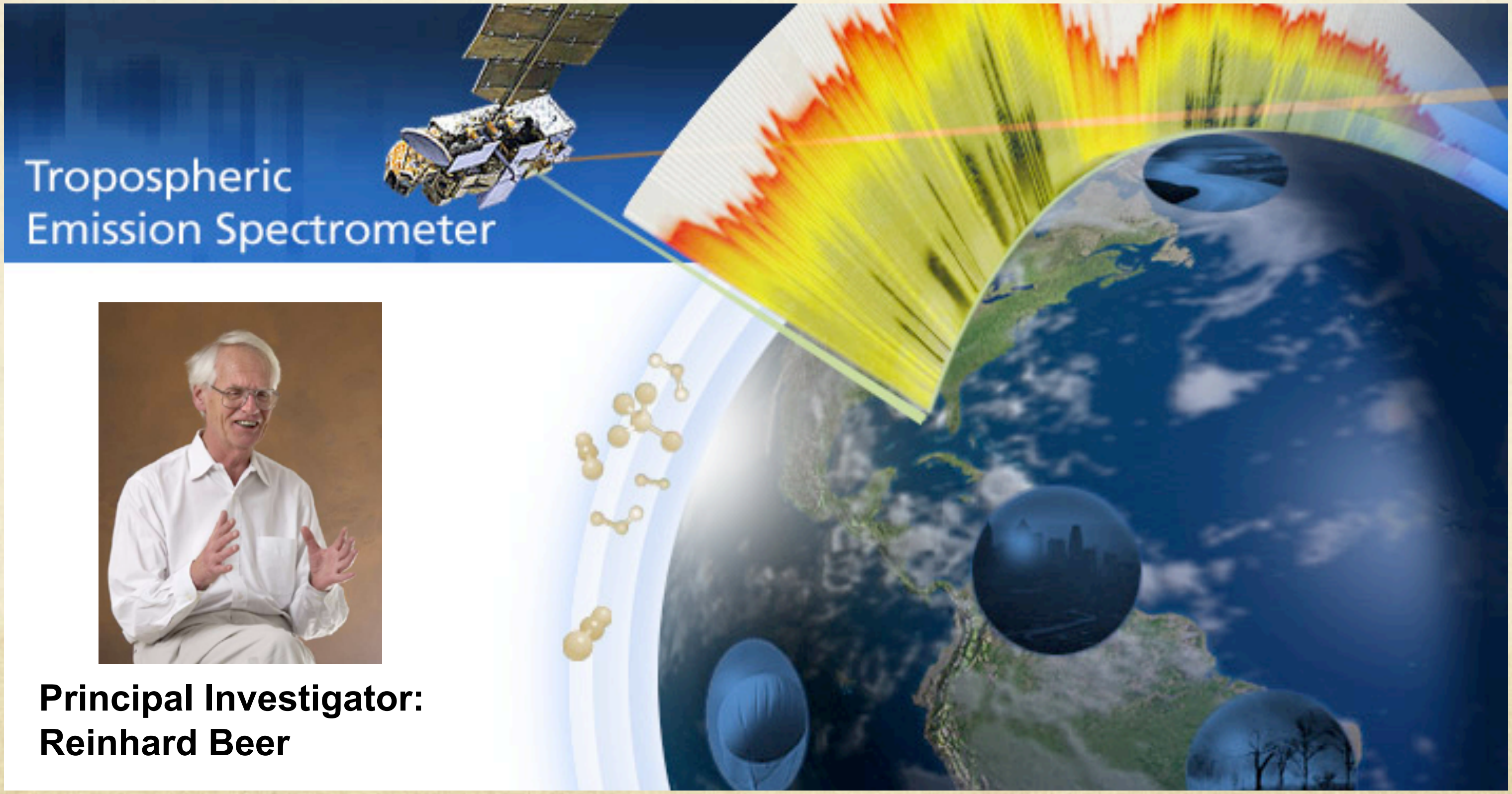
The best tropospheric ozone estimate that we had…



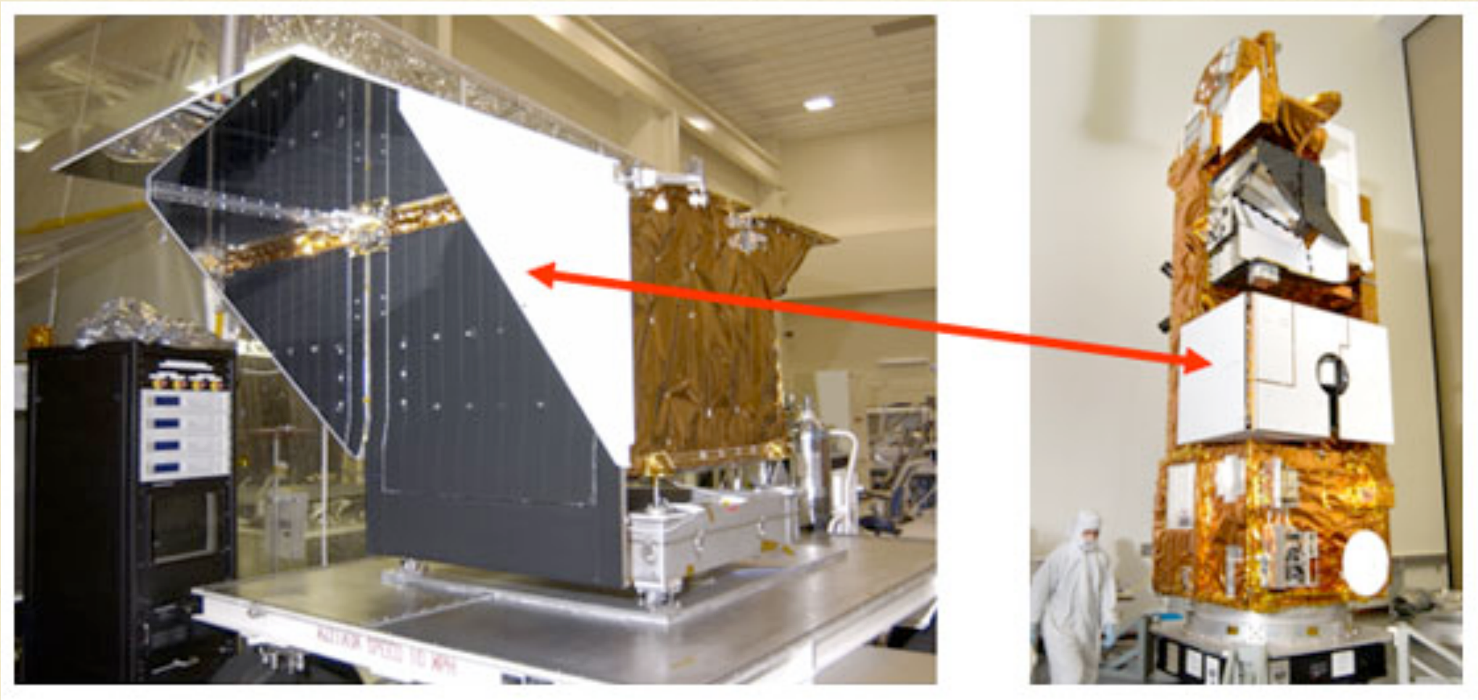
- Measure total amount
- Estimate amount in stratosphere
- Difference (small number) is amount in troposphere

New measurements

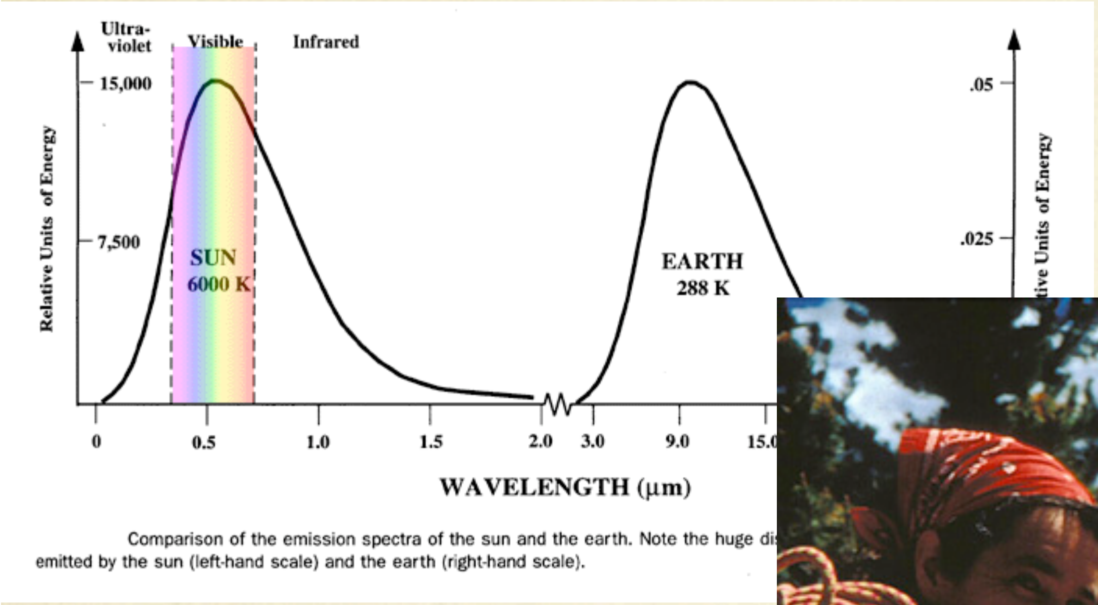
- TES actually measures the amount in the upper and lower layers of the atmosphere



A little bit about TES



How we measure

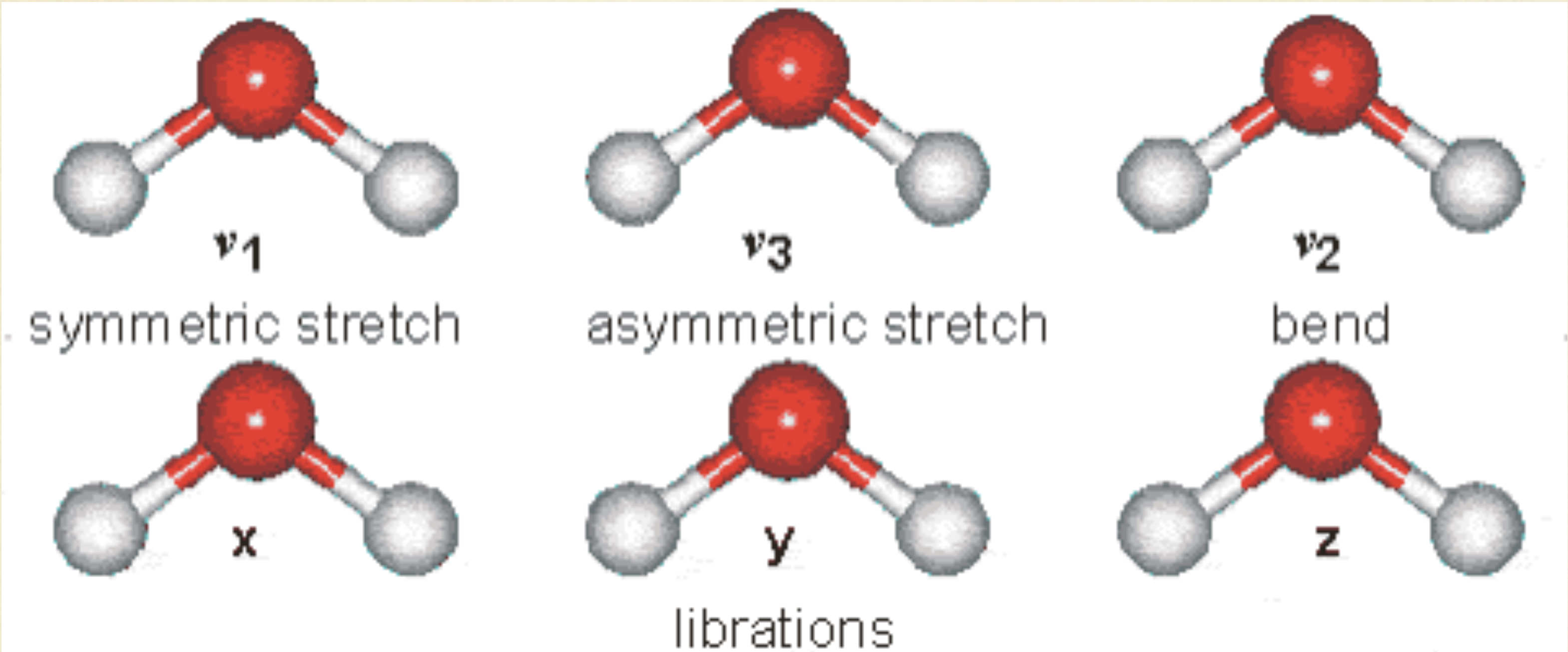


Comparison of the emission spectra of the sun and the earth. Note the huge di emitted by the sun (left-hand scale) and the earth (right-hand scale).

Ockhams-axe.com

lasp.colorado.edu

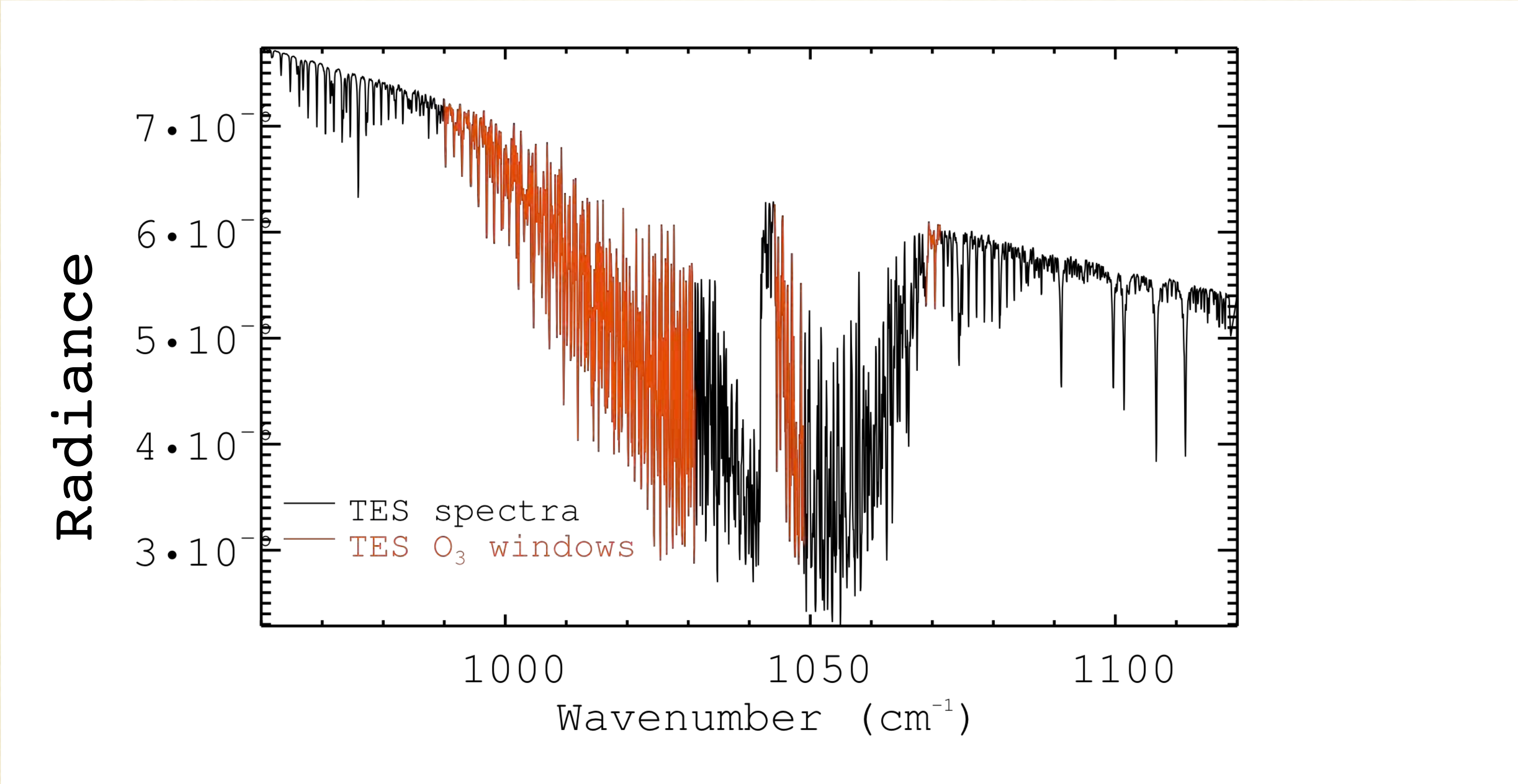
Molecules absorb energy



www.isbu.ac.uk

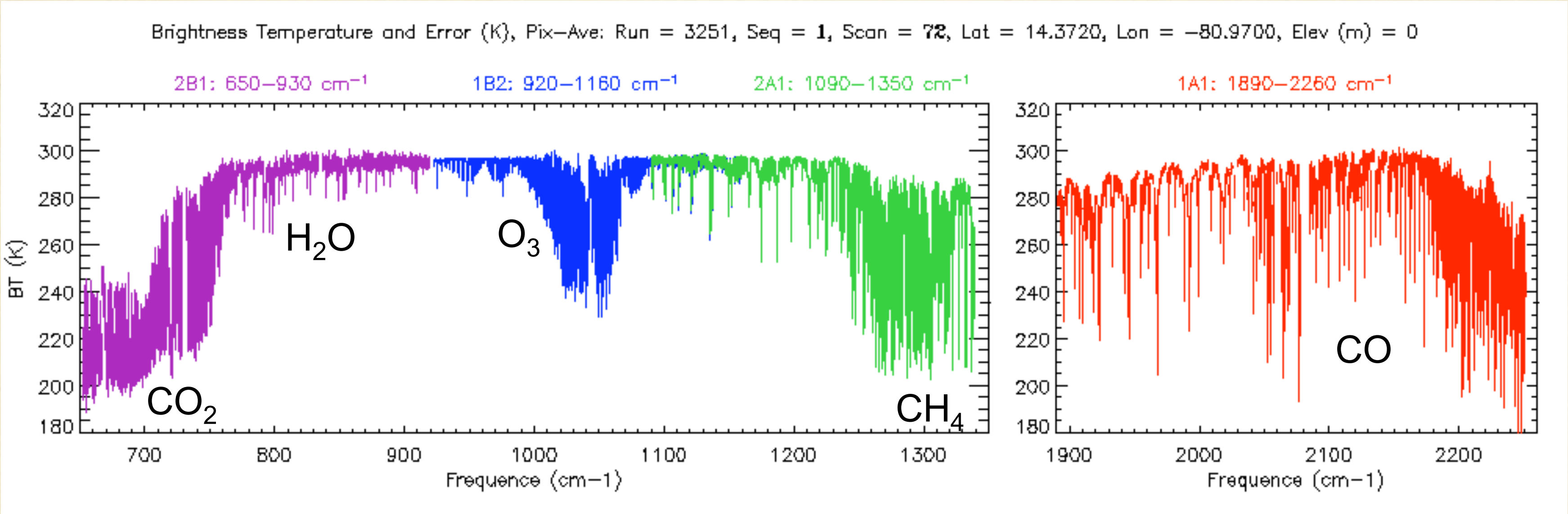
- Amount of energy is directly tied to wavelength of light

Using lines in TES retrievals



- Many lines are used together to get as much information as possible on the profiles of gases
- Use ‘optimal estimation’ technique – matrix math and fast computers

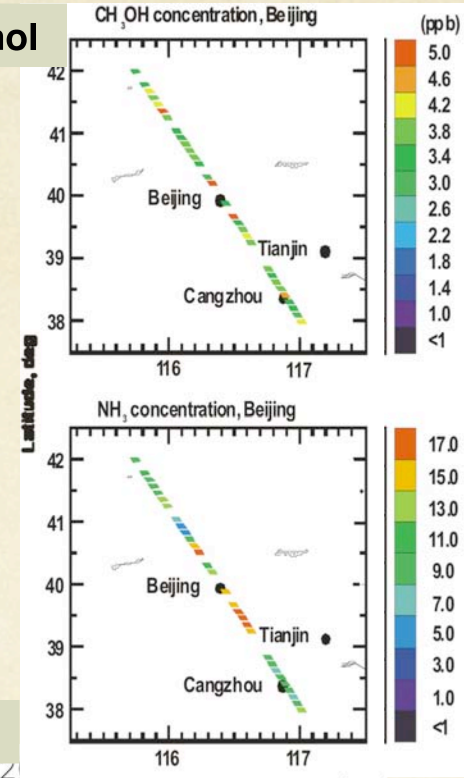
TES spectra



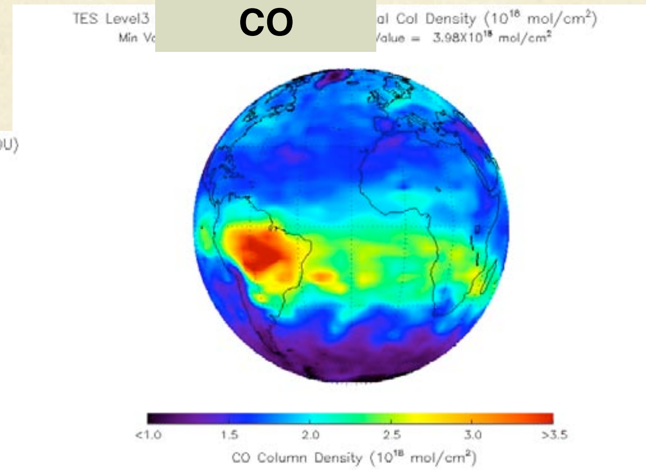
- Many chemicals can be measured at these wavelengths

TES measures a number of chemicals

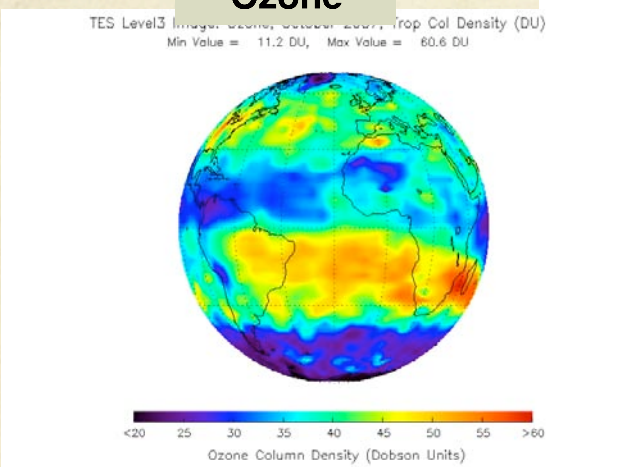
Methanol



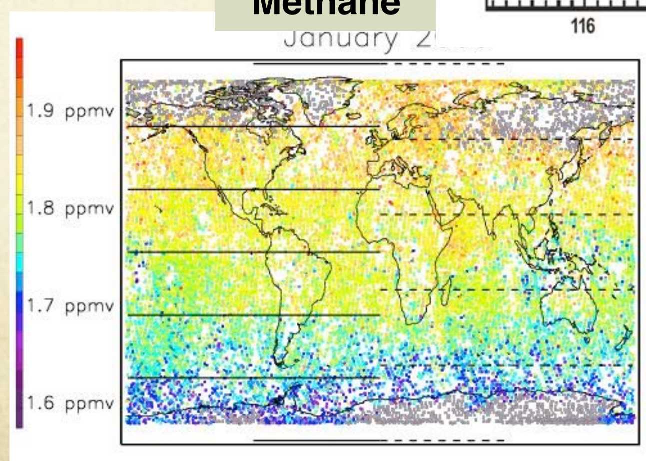
CO



Ozone

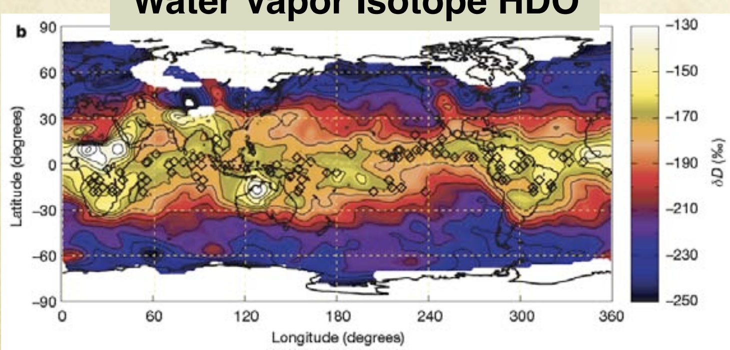


Methane



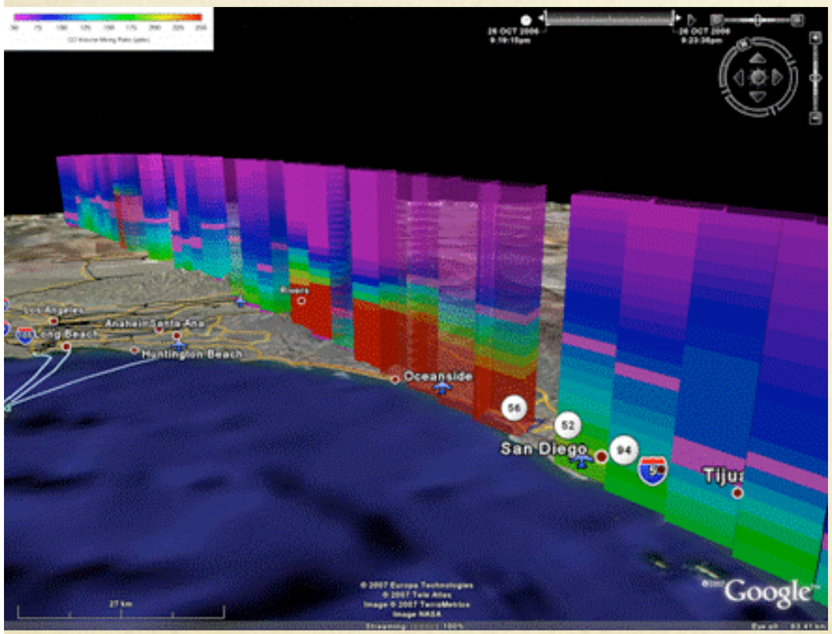
Ammonia

Water Vapor Isotope HDO



TES has flexible patterns

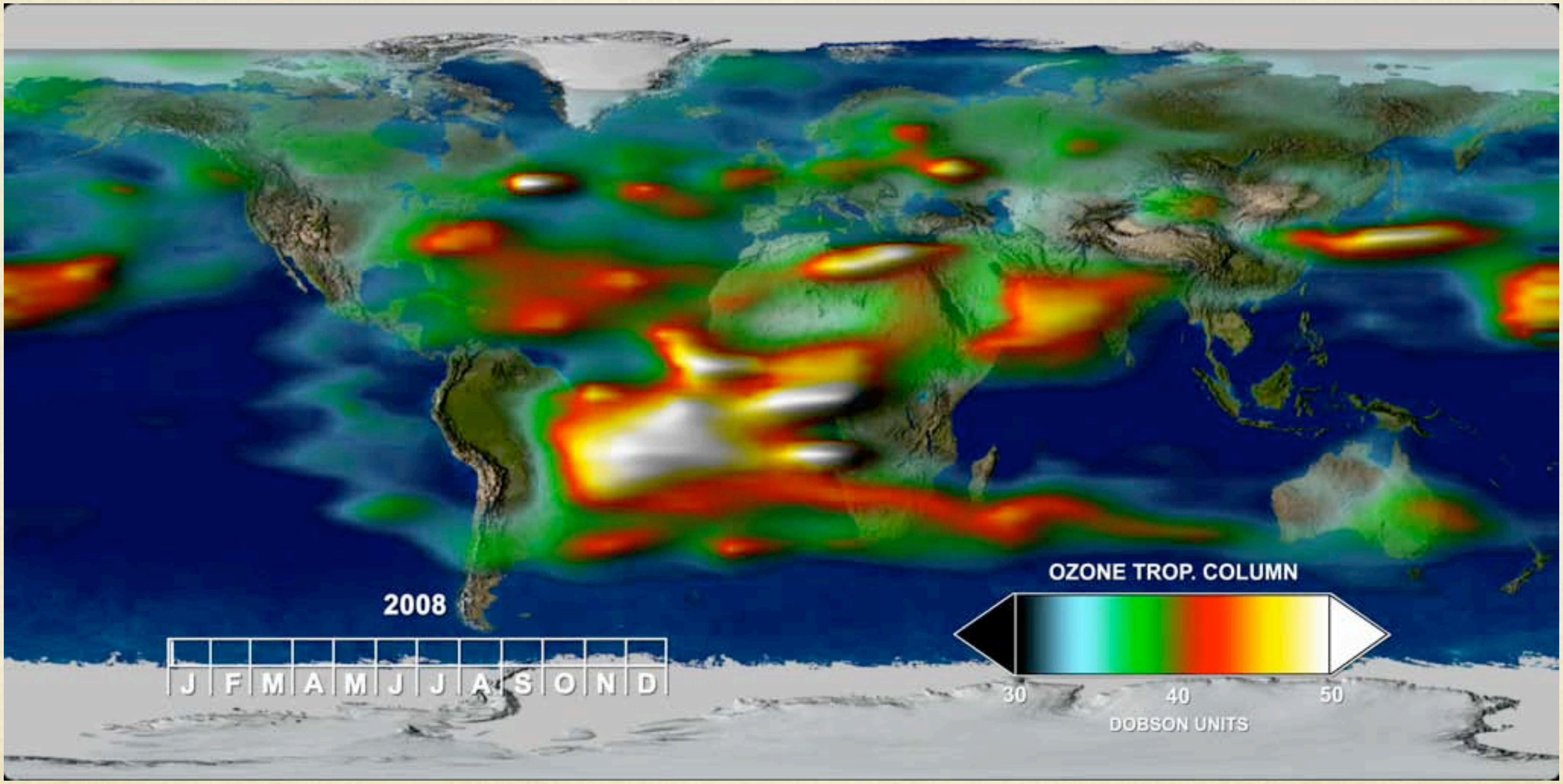
Special Observations –
dense sampling,
limited coverage



- Why? Data volume and instrument lifetime

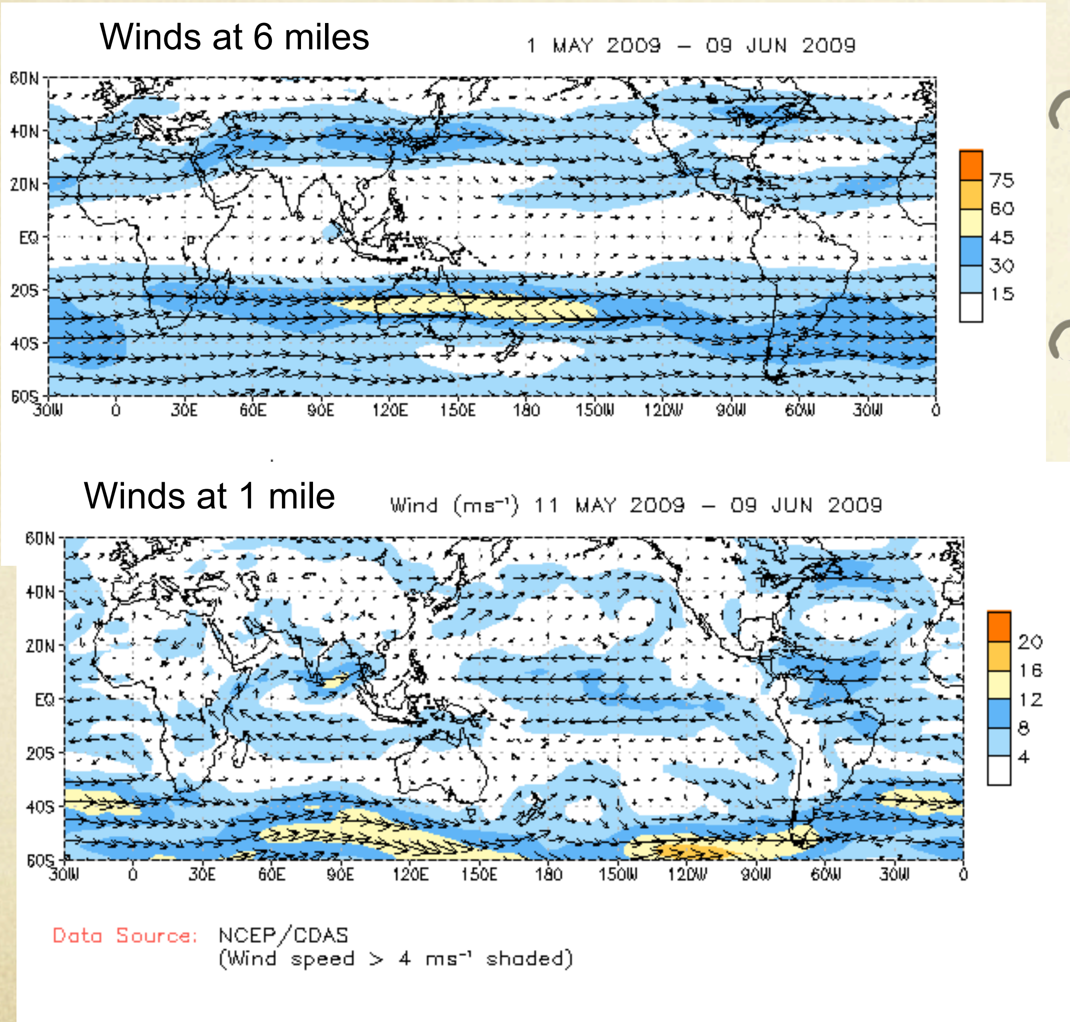
Global Survey – every other day, 180km spacing of measurements

TES tropospheric ozone



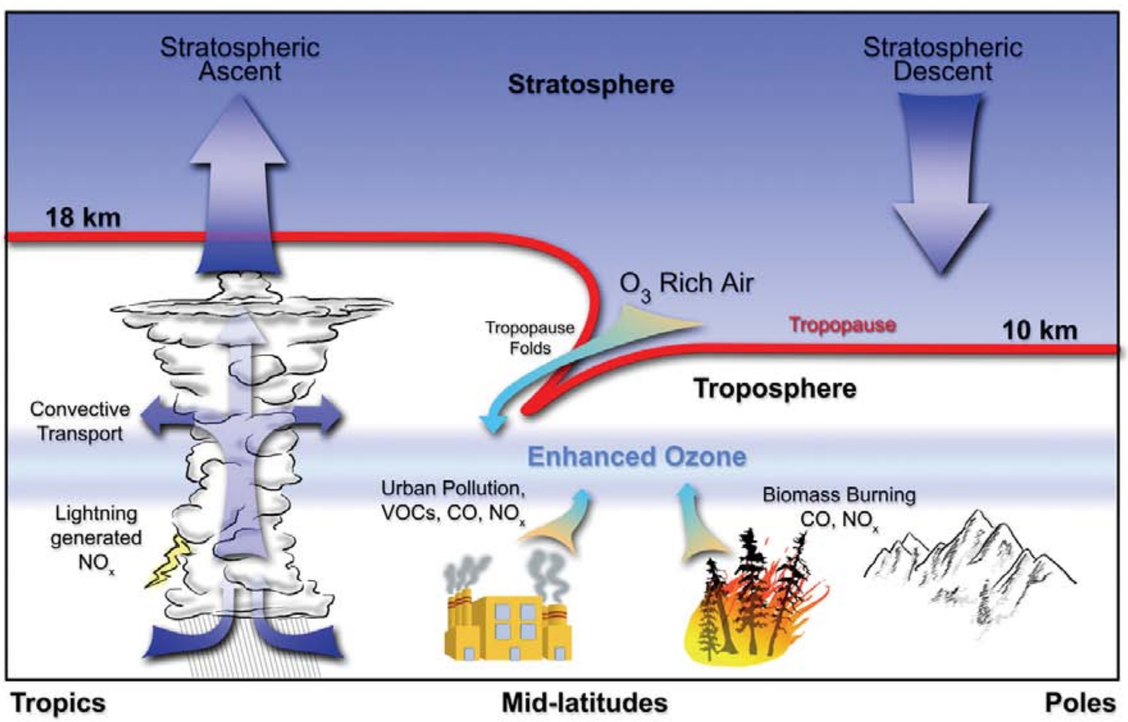
Created by Vince Realmuto, JPL

What changes the ozone concentrations?



- Pollution travels all around the globe
- Air moves from one side of the US to the other in 3 or 4 days - similar across the Atlantic Ocean

Other processes happening too

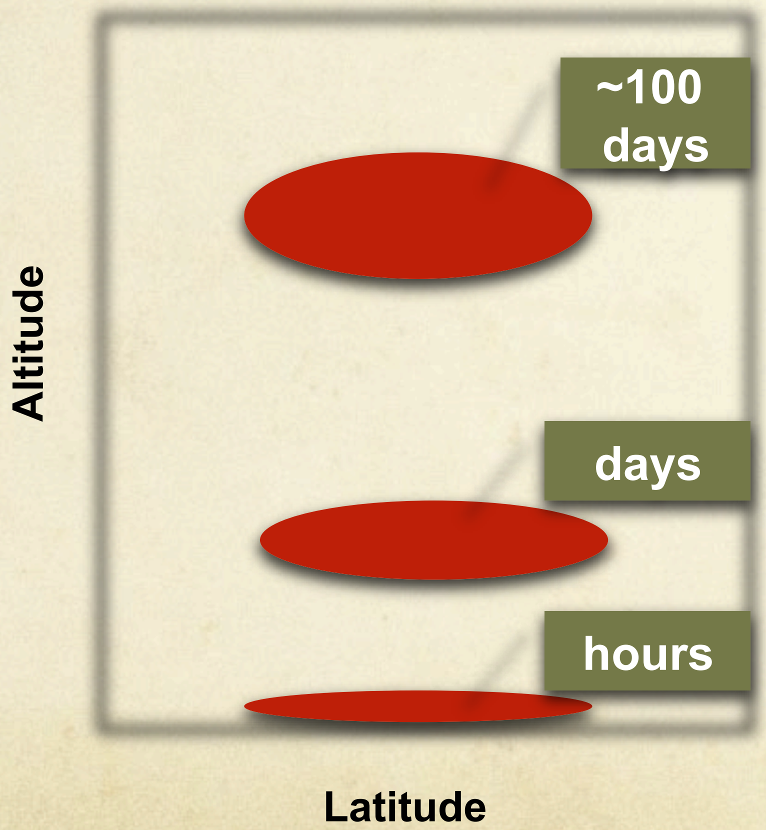


Aura project office

- Dilution and reaction while being transported
- Lightning adds NOx!

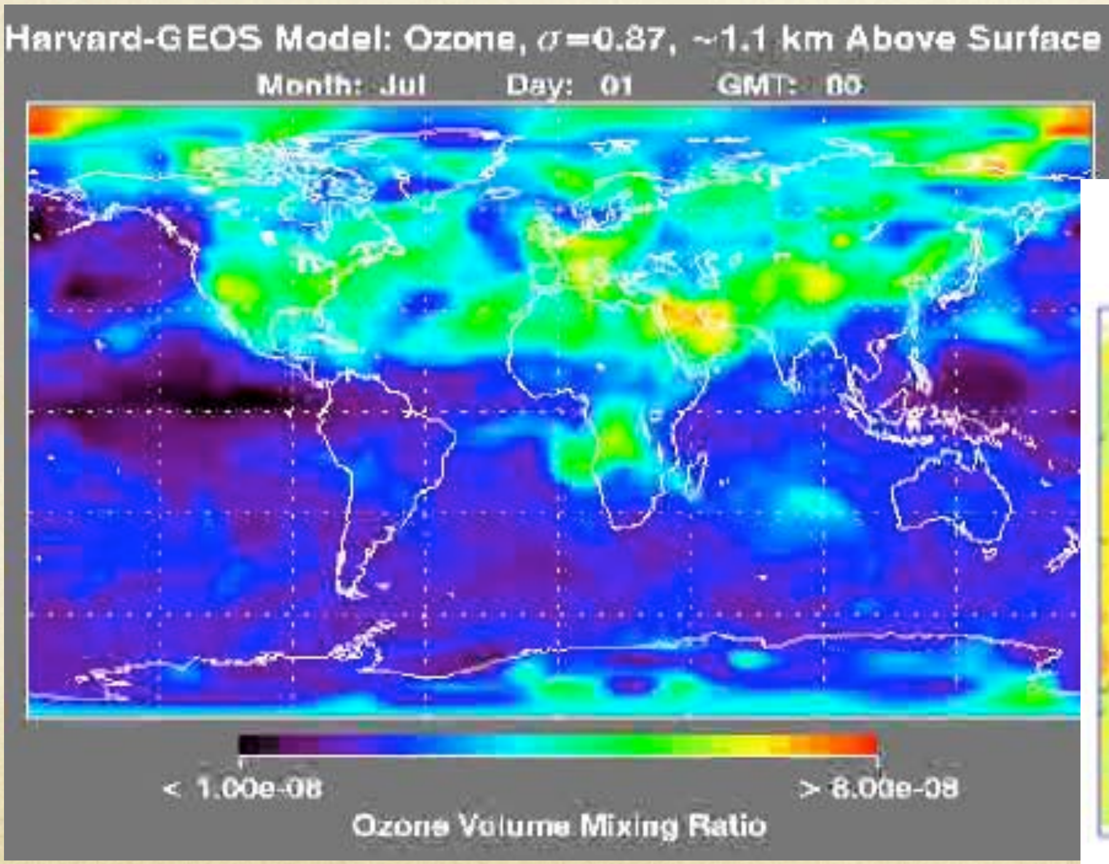
Chemistry is at different speeds

How long does ozone last?

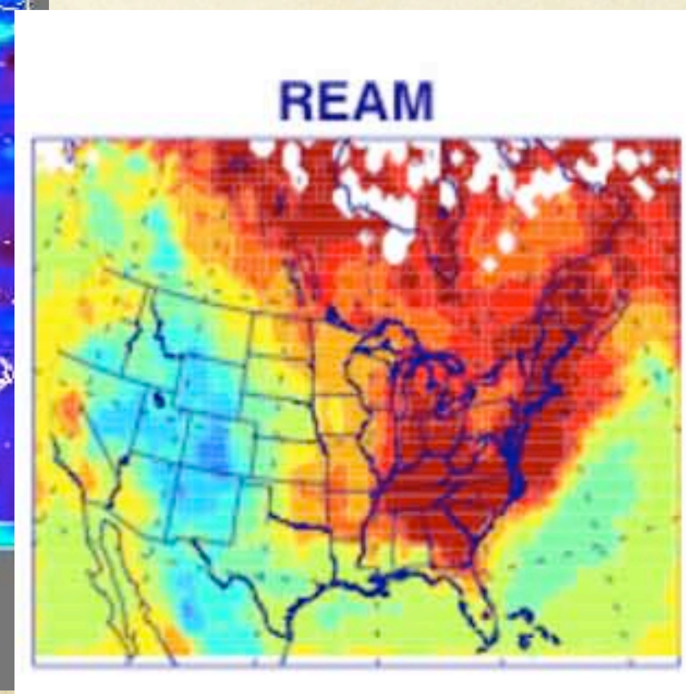


- The chemistry of ozone a few miles above us is slower – there is less NO and NO2, so ozone forms and decays less rapidly
- This means it lasts for more days, or has a longer lifetime
- In the movie, we saw the ozone that lasts for days

Global and regional models are important tools in our work

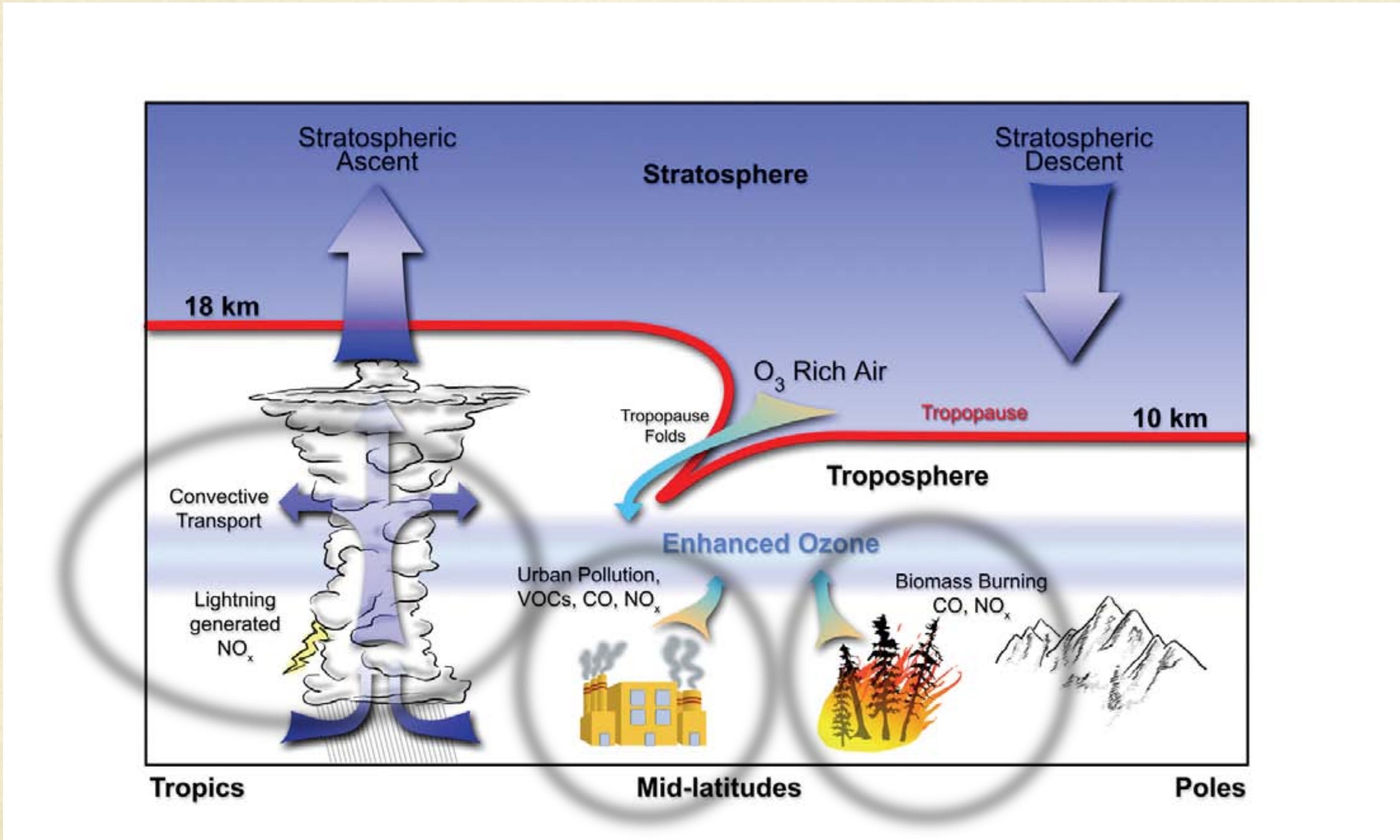


D. Jacob, Harvard

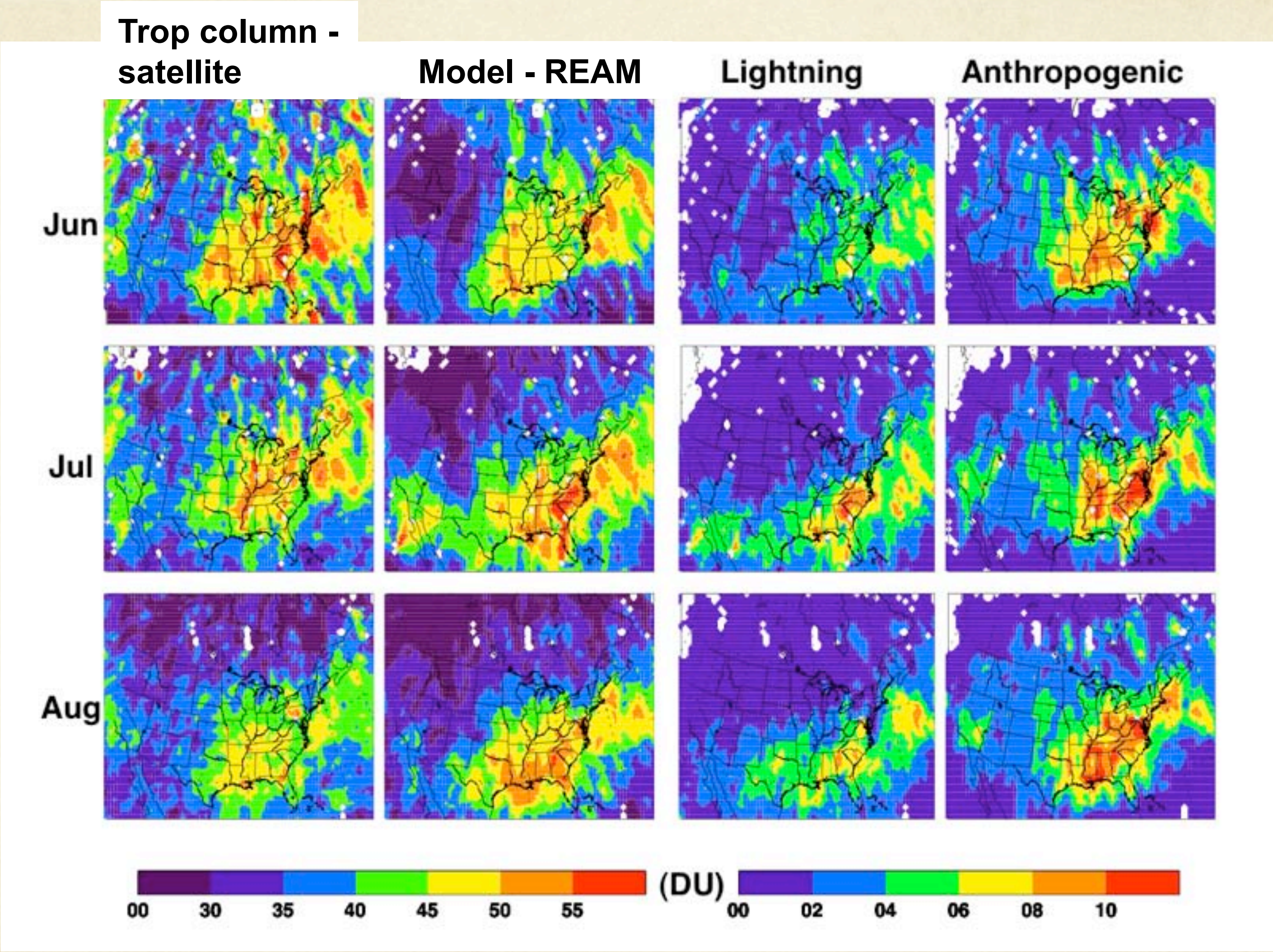


Y. Choi

Science analysis using TES

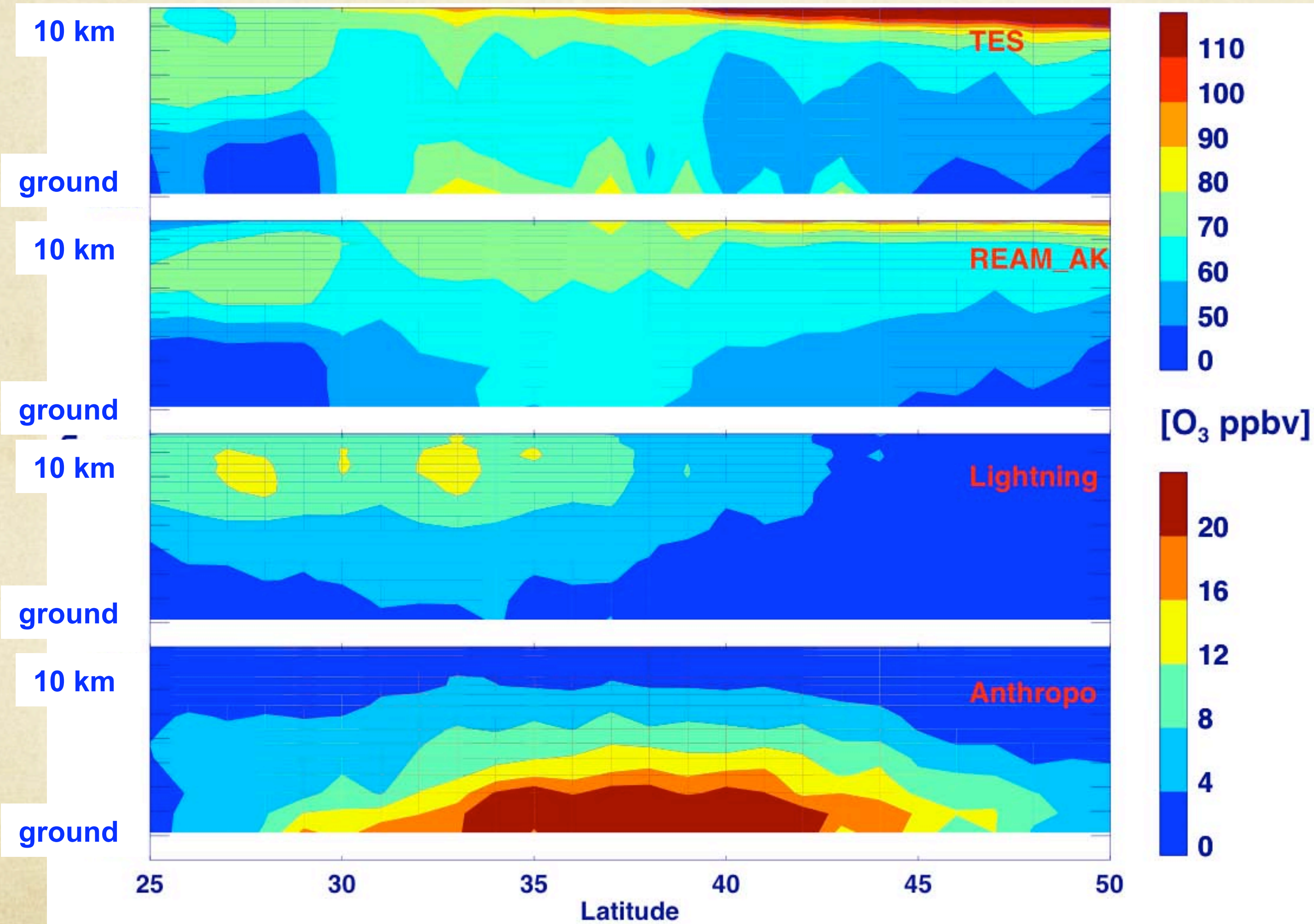


Tropospheric ozone over the US: how important is lightning?



Y. Choi

Lightning is very important in the upper troposphere.



Satellite

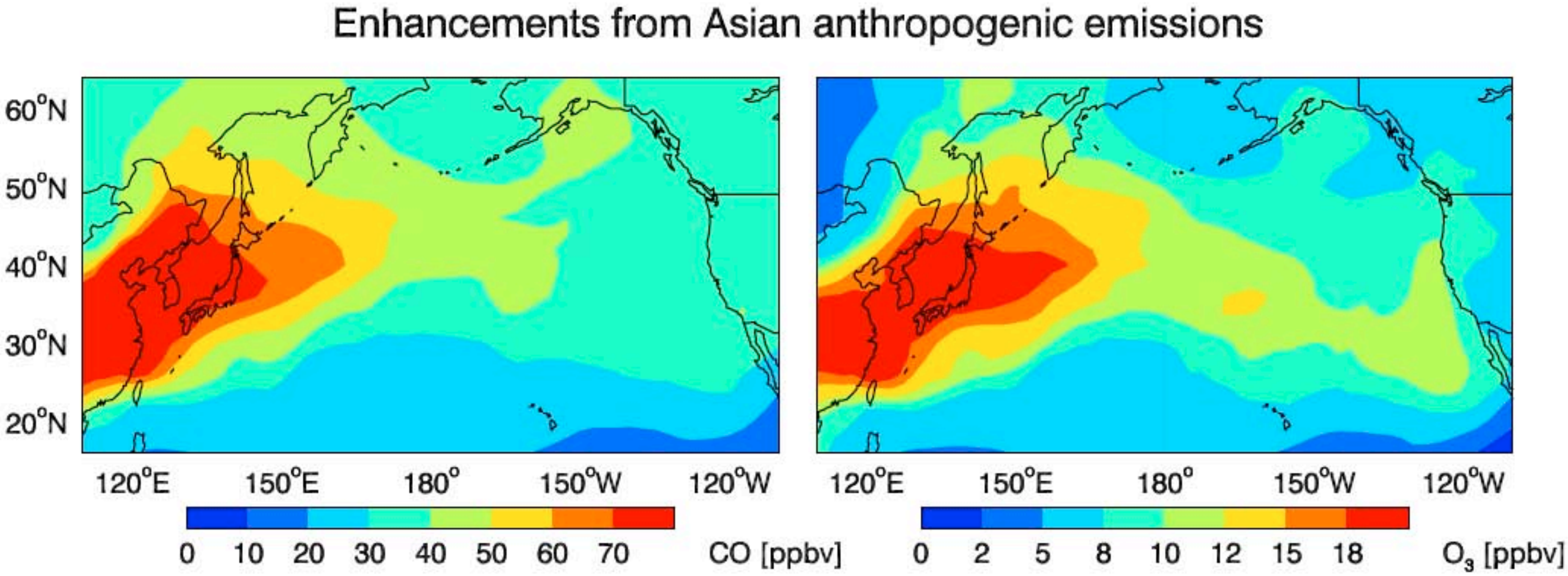
Model smeared like satellite

Lightning's contribution

Human's contribution

Y. Choi

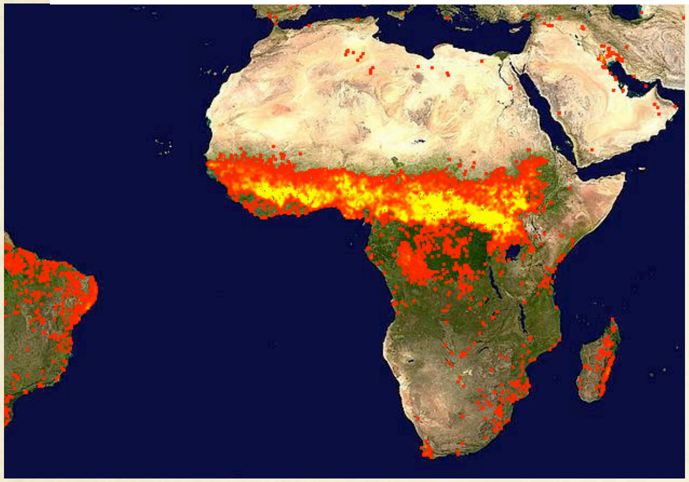
How far across the Pacific do we see the impact of Asian pollution?

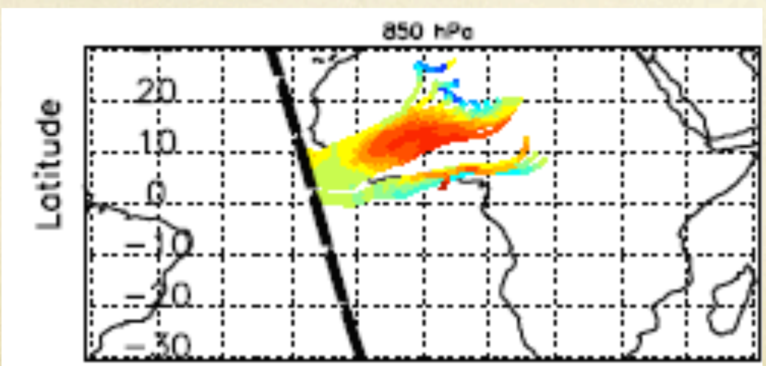


Zhang et al, 2008

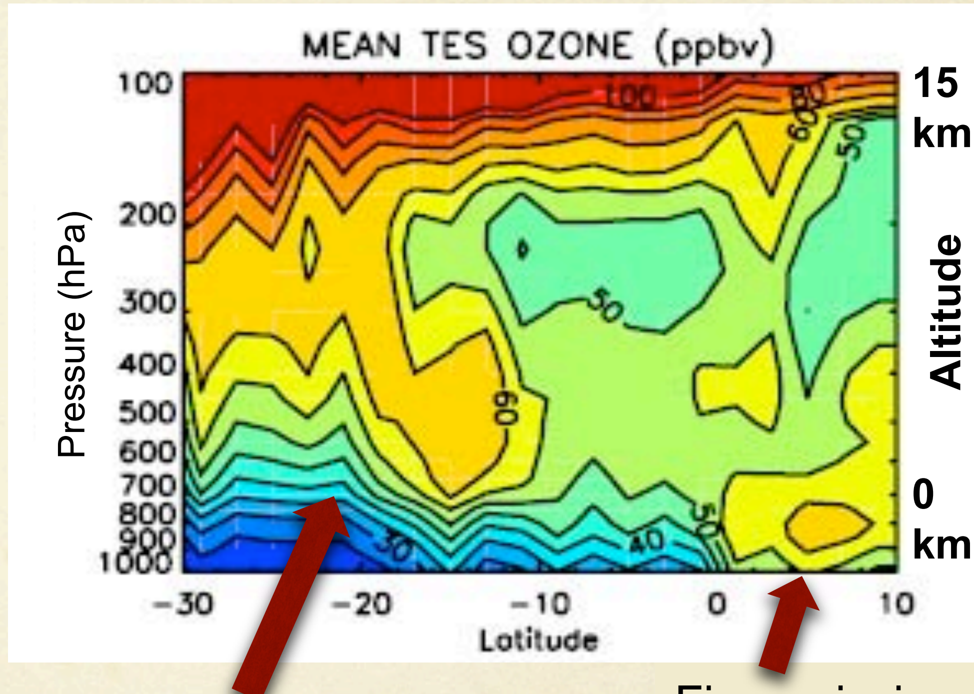
The impact of fires on tropical ozone

MODIS firecounts Jan 11-21, 2005





Where the air TES measured came from



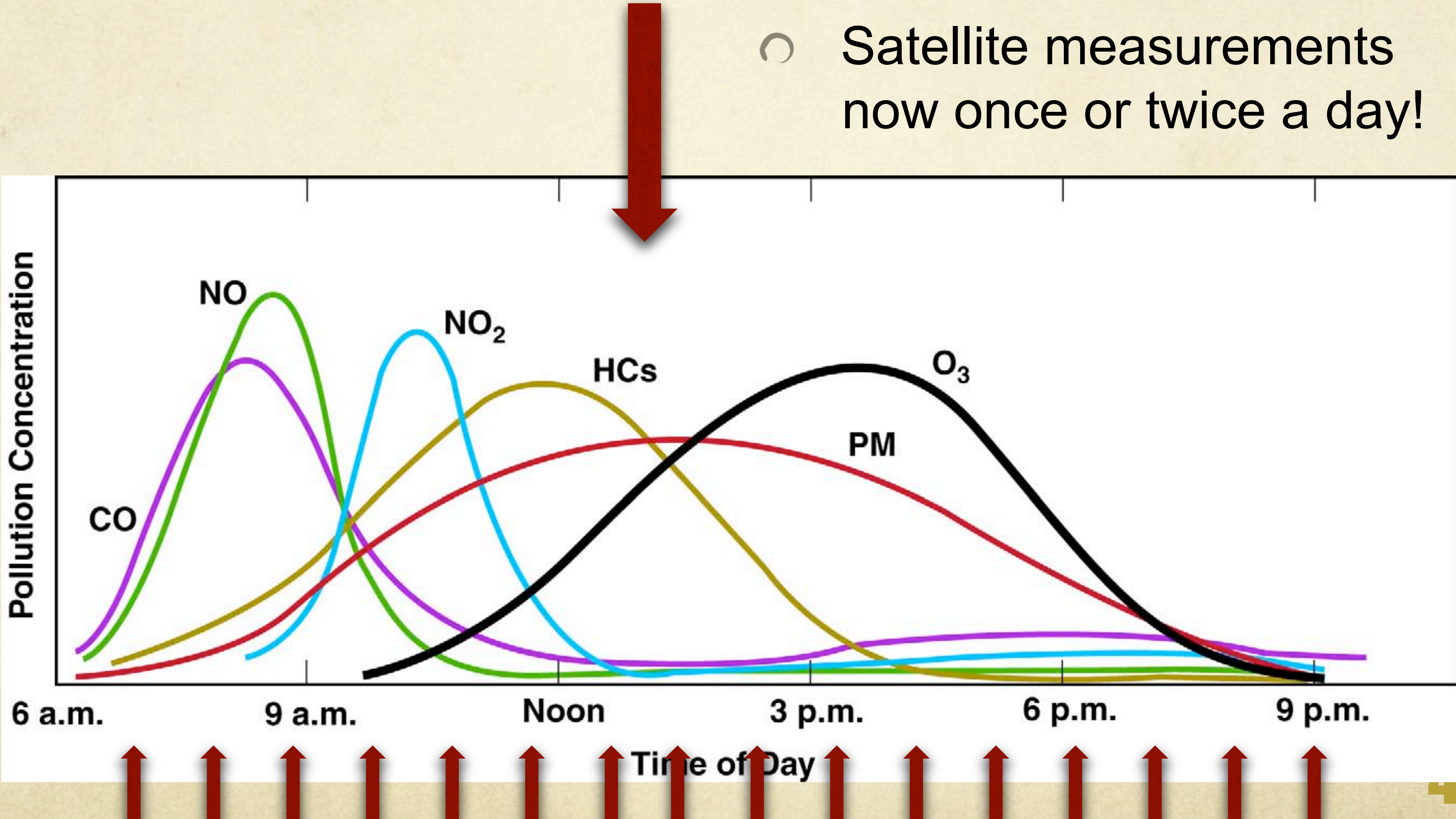
Likely to be formed with lightning Nox

Fire emissions lead to ozone near the surface

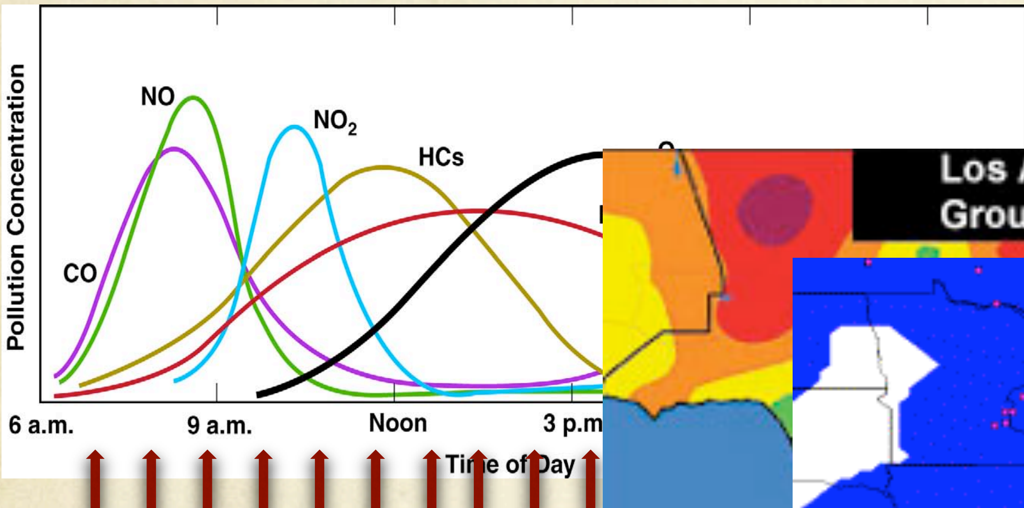
Jourdain et al., 2007

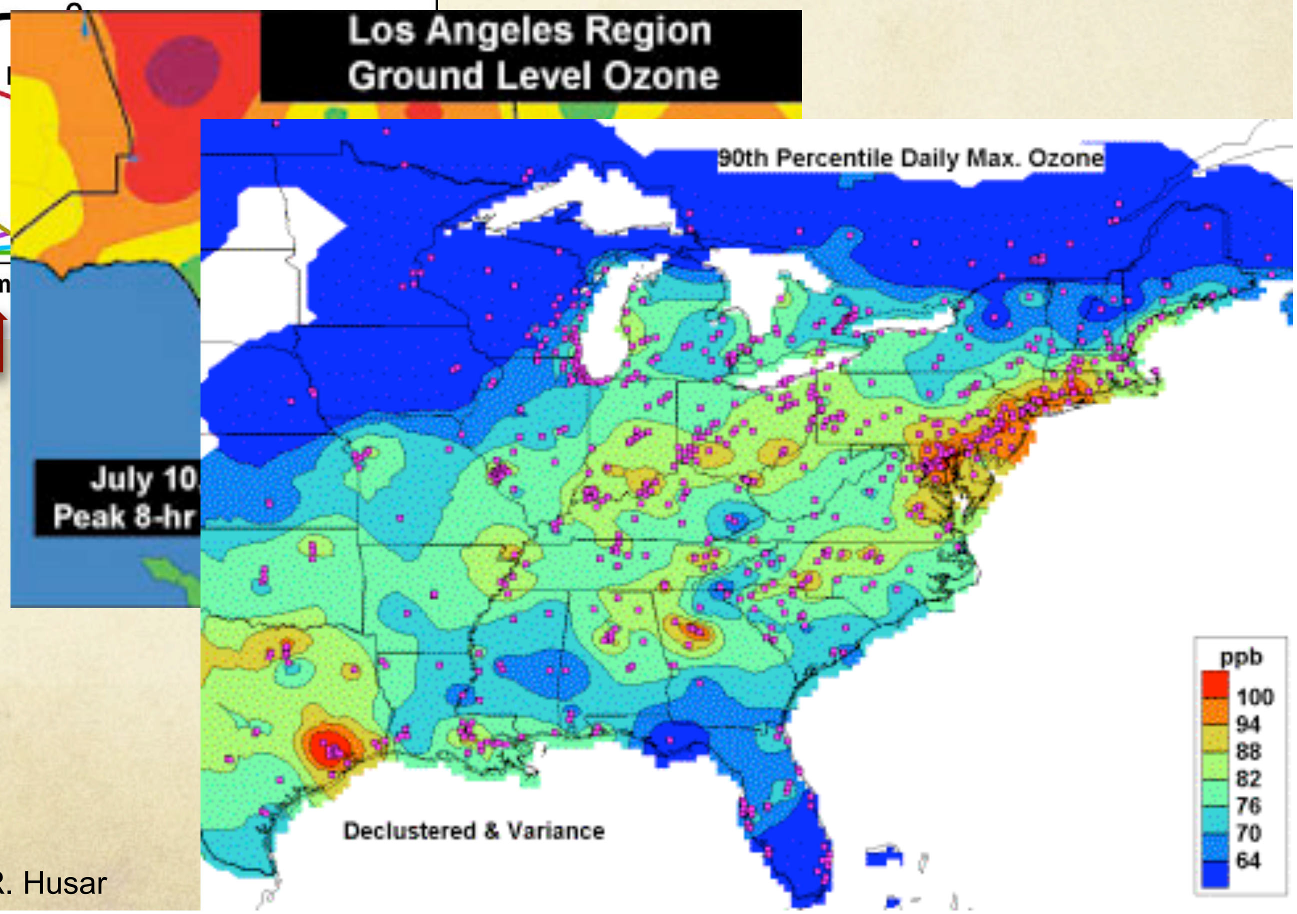
Where do we go from here?

- Satellite measurements now once or twice a day!



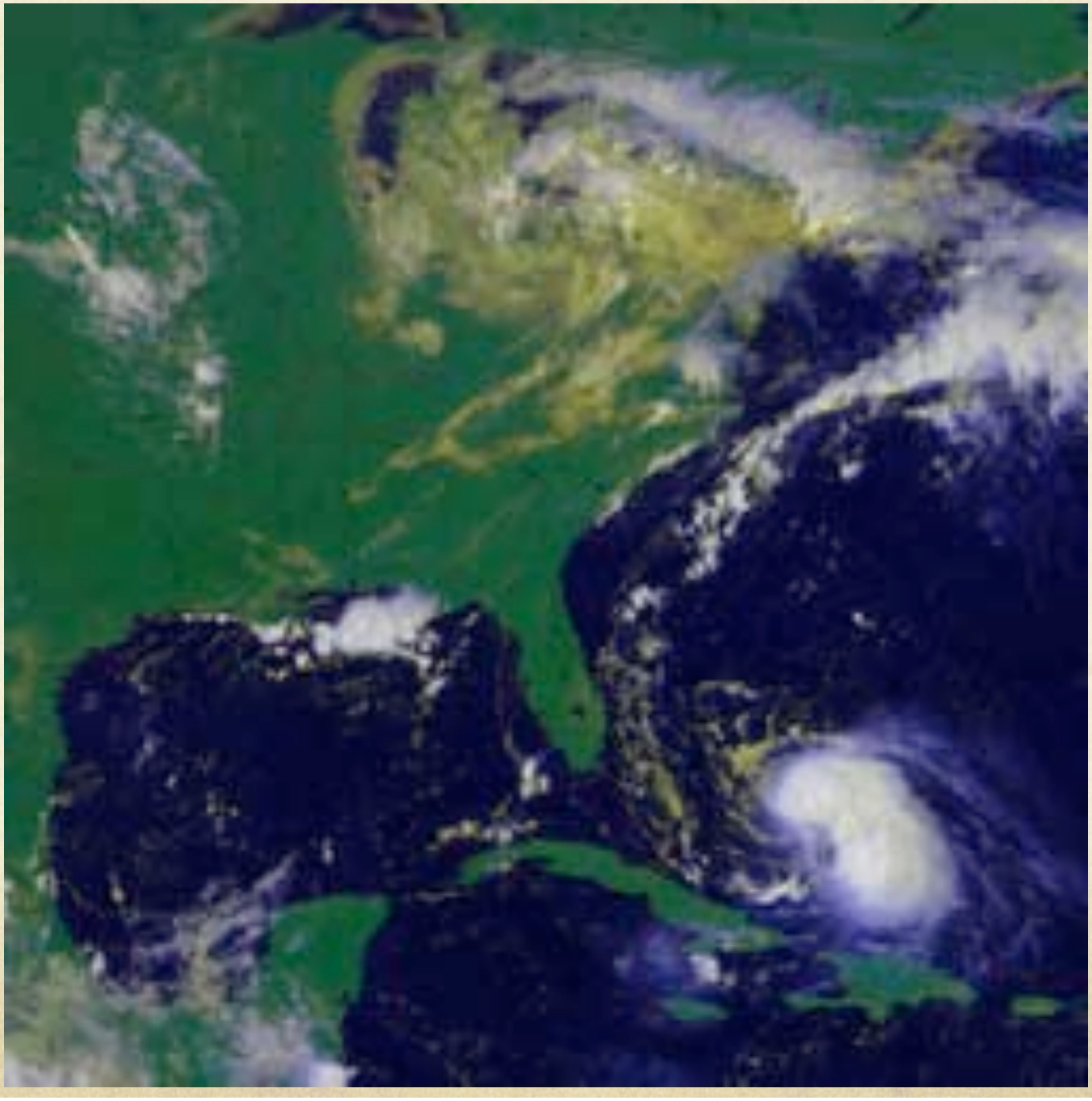
The next leap forward





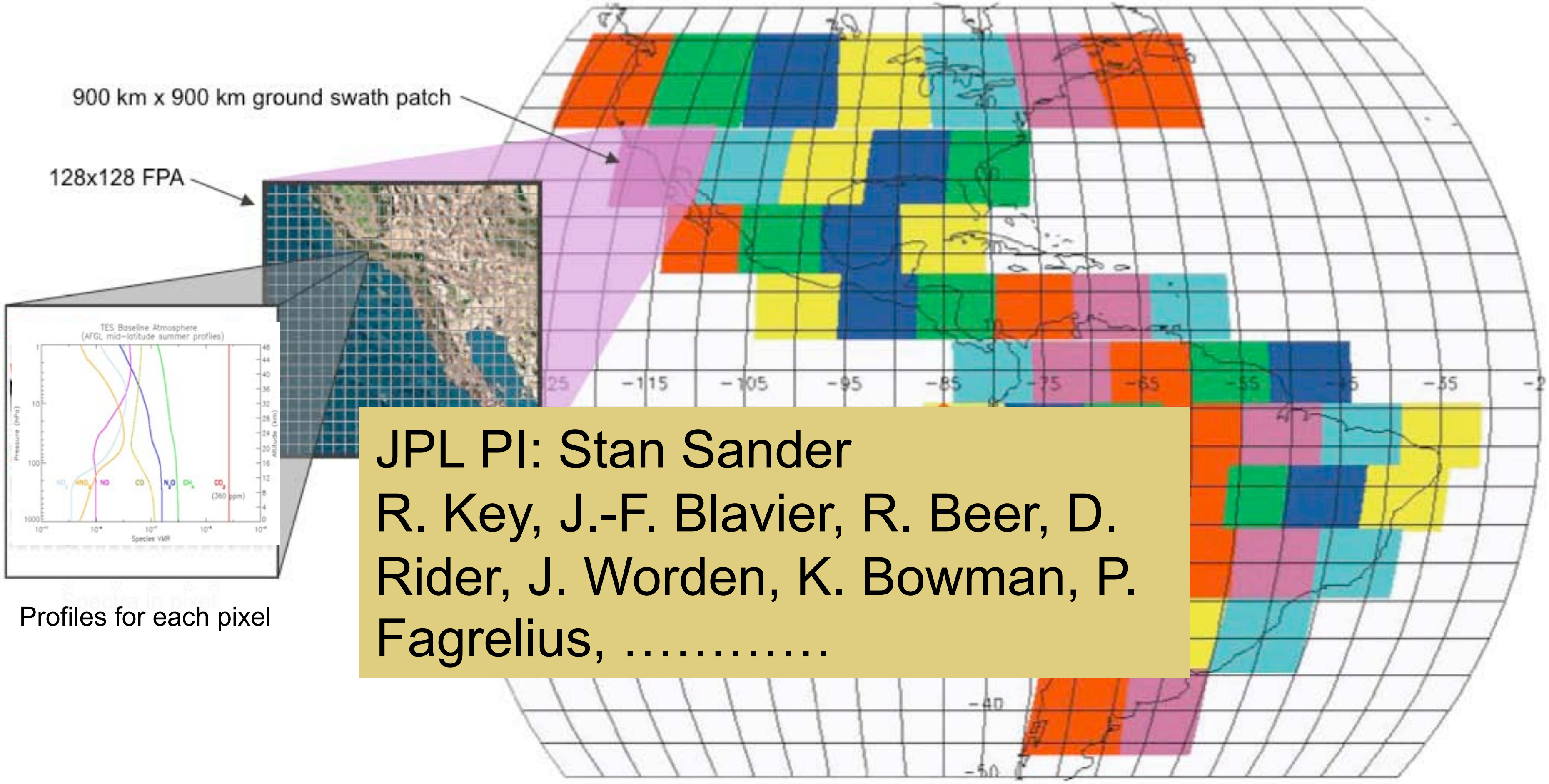
R. Husar

We see weather that way



GSFC visualization

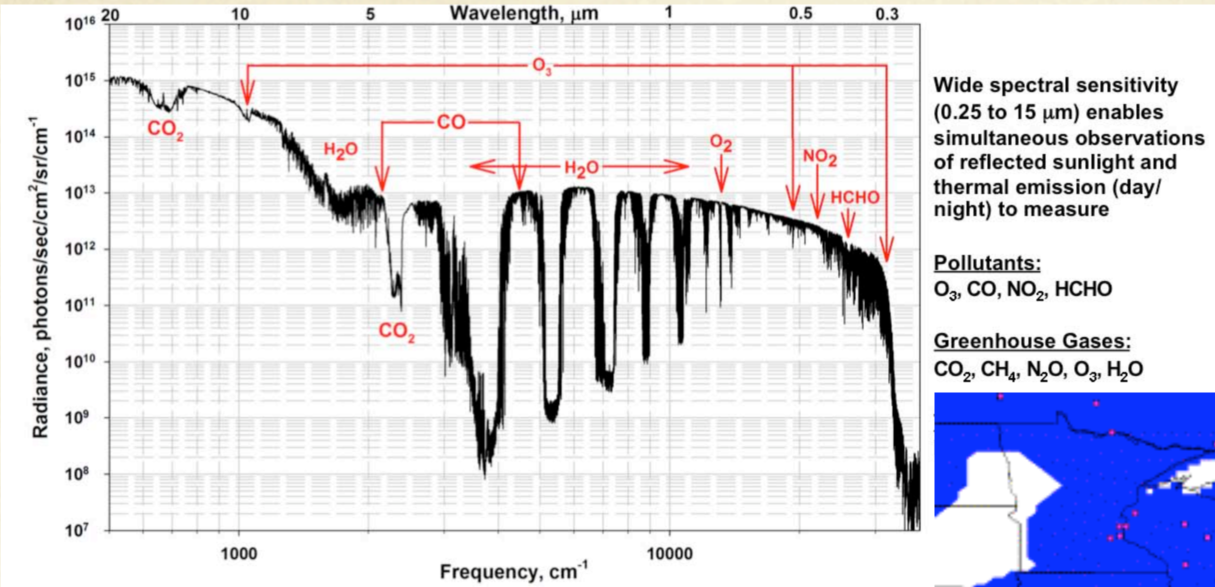
GEO-CAPE: A ‘weather satellite’ for air pollution!



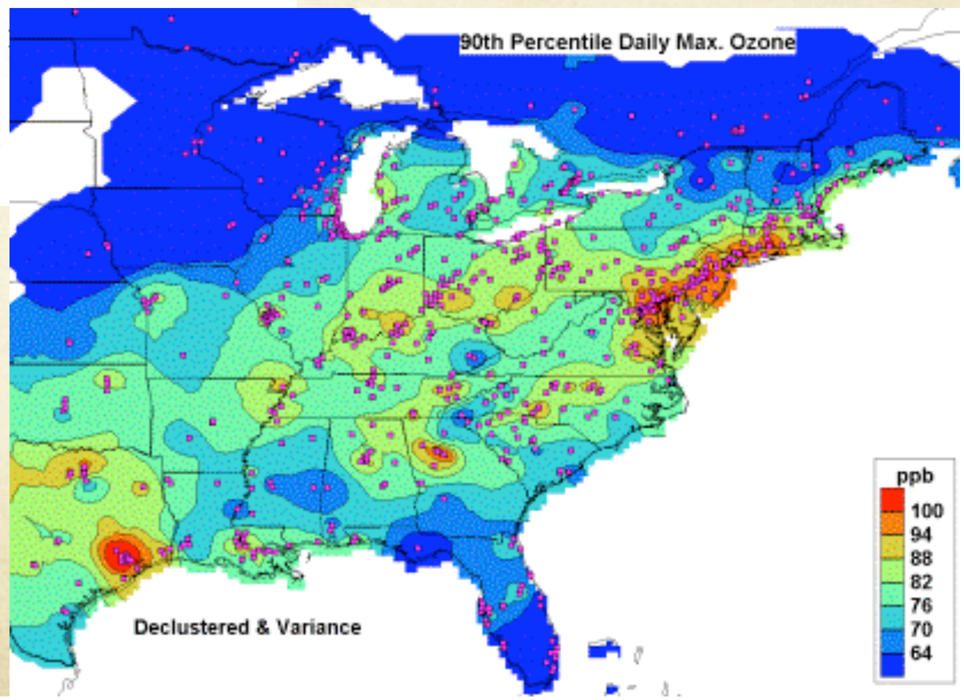
Profiles for each pixel

JPL PI: Stan Sander
R. Key, J.-F. Blavier, R. Beer, D. Rider, J. Worden, K. Bowman, P. Fagrelius, …………

Measure key molecules frequently



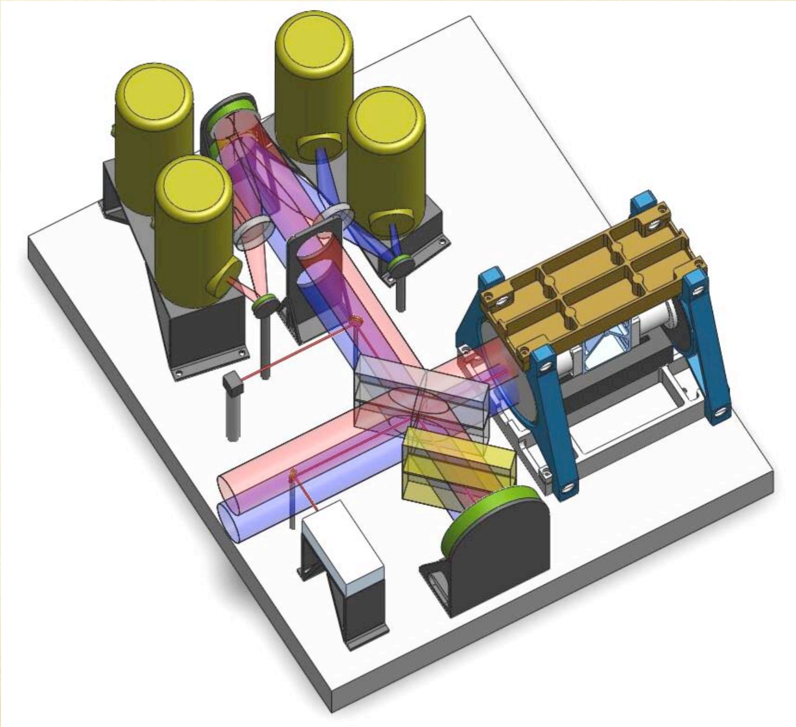
Measure key pollutants: ozone, CO, NO2, hydrocarbons (HCHO, CH3OH) at hourly intervals



Challenges

- Handling the data
- 128 x 128 = 16384 measurements per minute
- TES has 3000 per day (in 1440 minutes)
- Yikes!!!!
- Throw out cloudy scenes to reduce data somewhat, maybe done on-board
- Need speedy algorithms and computers

- Demonstrating the instrument



Summary

- Los Angeles was a key region for many smog discoveries
- Our air pollution problems has been drastically reduced since the 50's.
- There are many cities across the world struggling with pollution problems
- Satellite measurements let us see the larger picture of ozone concentrations, but mostly above the surface
- We are developing missions that would measure air pollutants more often, and with better sensitivity

THANK YOU